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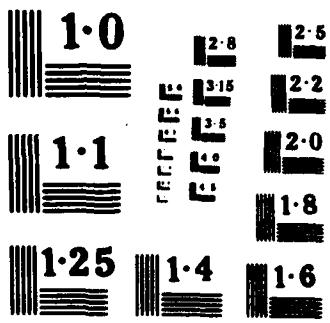
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AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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Space System Applications to Tactical Operations

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Conference Proceedings No.344

SPACE SYSTEM APPLICATIONS TO TACTICAL OPERATIONS

Papers presented at the 46th Symposium of the Avionics Panel held at NASA Langley Research Center, Hampton, Virginia, USA, 17–21 October 1983.

THE MISSION OF AGARD

The mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Programme and the Aerospace Applications Studies Programme. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

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INTRODUCTION

Organized by Dr Theodore Von Karman in 1952 AGARD was originally called the Advisory Group for *Aeronautical* Research and Development. In 1957 during the Seventh General Assembly of AGARD Dr Hugh Dryden who was the Director of the forerunner of NASA the National Advisory Committee for Aeronautics, described the impact of the first US satellite launched two months prior to that meeting.

From then on AGARD has had active work going on in studies in the space arena. For example, at the Eighth General Assembly held in Denmark in 1958 Dr Norman Ramsey, who is now a Nobel Prize winner, and was at that time, Science Advisor to the Secretary General of NATO, chaired the major round table discussion which was entitled "Impact of Space Technology on Research and Development". At the Eleventh General Assembly, which was held in July of 1961, in Norway, the round table discussion was on scientific aspects of space technology, and at this eleventh session an interpanel space information group was established that was chaired by Dr Eb Rechtin, ex Chairman of the Avionics Panel, ex Assistant Secretary of Defense and currently President of the Aerospace Corporation.

In 1965 AGARD changed its name from aeronautics to aerospace, so we now have officially the title Advisory Group for *Aerospace* Research and Development. Recently AGARD has reemphasised space activities because during the past two decades space technology, space systems and space resources have been developed which clearly can contribute to increasing combat capability and efficiency in the tactical arena. We have military communications using space assets which are very important in the tactical world for command and control. The various weather satellites permit a much more accurate and more timely weather forecasting and again very important for tactical military applications, and the eighteen satellite Global Positioning System, in fact, revolutionized the future of navigation and bombing. So, currently I believe that there is an increasing appreciation not only by the tactical military community but also by the research and development community regarding the impact that space will have in future tactical operations.

NASA Langley Research Center was a very appropriate site for this Symposium. Langley AFB is the home of the US Tactical Air Command. NASA Langley Research Center since 1917 has been a pioneer in space exploration, space technology and applications. Bringing together the tactical military community and development community from all the NATO nations to discuss Space System Applications to Tactical Operations was the purpose of this Symposium.

This particular symposium brings into focus and characterizes those attributes of space systems which contribute to the effectiveness of tactical military applications. More specifically, an overview is provided of what are the tactical needs and requirements that can be satisfied using space assets. Both the current existing systems as well as the potential new systems that are coming onstream later on in the century are characterized. Both the advantages and limitations of space systems are assessed and finally future trends which should be of particular interest to the research and development community are discussed.

It was indeed an honor and a pleasure to be general chairman of this symposium. It was a pleasure because the programme committee did such outstanding work to assemble such distinguished speakers for the overview session and to identify and encourage the authors who presented papers. I would like to acknowledge particularly the work of Mr Joe Statsinger for writing the Technical Evaluation Report and editing the Conference Proceedings and Mr Bill Dove for orchestrating the physical facilities and other amenities at NASA Langley Research Center.

The Conference Proceedings are contained in two volumes. CP 344 contains the Technical Evaluation Report, the unclassified papers, and unclassified abstracts of classified papers. The NATO Secret Supplement, CP 344(S), contains the Technical Evaluation Report, the abstracts of unclassified papers, classified papers, all questions and answers that followed the presentations of papers, summaries of discussion periods, and the list of participants.

Max T. Weiss

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Reference

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EXECUTIVE SUMMARY

The following summarizes the significant observations and recommendations from the Technical Evaluation.

Observations

It was noted that a number of areas would benefit by additional effort.

1. Communication between users and developers should be improved in order to:

   (a) Establish better quantification of requirements.

   (b) Expose the developers more clearly to the exigencies of battlefield applications.

   (c) Identify the needs for flexibility.

   (d) Improve the familiarity of the using community with space system operational characteristics.

2. Steps should be taken to improve interoperability among existing and planned systems in the NATO environment in order to enhance the utility of these broadly applicable systems.

3. The participation of the various NATO nations in cooperative development and application of space systems should be increased.

4. *Alternative techniques for procurement and fielding* of space systems should be developed and evaluated considering that small quantities and high unit costs will continue to be characteristic of these systems.

5. The impact of retrievable boosters on the development and application of space systems should be further studied.

6. The development of suitably configured ground assets should be pursued for the purpose of assuring maximum survivability and utility.

7. Areas should be identified where further advances in technology are desirable, in order to support future systems *having greater capabilities than systems currently available.*

8. Future activities should stress the importance of overall systems engineering and systems macro-architecture to assure that all of the elements involved in these complex systems are properly interfaced and that systems designs for individual space systems interact with each other for the overall greatest effectiveness in providing support to military operations.

Recommendations

1. Conduct a review of on-going and planned communication and navigation systems, both space and ground based. The review should focus on issues of interconnection and interoperability among all of these assets and the related architectural issues. The objectives should be to optimize the utility and survivability of the overall NATO capability.

2. Plan a symposium on space technology with the objective of defining initiatives which the NATO nations should pursue to increase the capability of future space systems.

3. Plan a symposium on the subject of space system macro-architecture. This should include questions of interoperability and survivability as major topics.

TECHNICAL EVALUATION REPORT

by

Joseph Statsinger
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INTRODUCTION

The 46th Symposium of the Avionics Panel was held at the H.J.E. Reid Activities Center of the NASA Langley Research Center, Hampton, Virginia, USA, 17 – 20 October 1983. The program chairman for the meeting was Dr Max T. Weiss of the Aerospace Corporation, El Segundo, California, USA. The papers presented and discussions conducted at the meeting are published in *Conference Proceedings CP 344 and CP 344 (Supplement).*

THEME AND OBJECTIVES

The advances in space technology and systems during the past two decades have led to the availability of resources which can contribute to increased combat capability and efficiency in tactical military operations. Military communications satellites such as the NATO and SKYNET series and the US COMSATS have demonstrated their effectiveness as elements of military command and control systems. The various weather satellites permit more accurate and more timely weather forecasting and have become important to all military operations. The 18 Satellite Global Positioning System which is currently under development may revolutionize weapon system navigation and guidance over the next decade.

The importance of space assets in supporting tactical operations is gradually becoming better appreciated by the leaders of the R&D community and by military leaders in the NATO countries. However, the full potential of these systems has not yet been realized. The intent of this symposium is to bring into focus and to characterize the attributes of space systems which contribute to the effectiveness of tactical military operations.

The objectives of the meeting are as follows:

- Provide an overview of tactical needs which are effectively addressed by space systems.
- Characterize the various existing and potential space systems with emphasis on those attributes which are most related to tactical needs.
- Assess the advantages and limitations of space systems in supporting combat operations.
- Investigate the interaction of space assets with ground and mobile resources and consequent operational issues.
- Discuss future trends in space technology and their relationship to evolving combat needs.

GENERAL DESCRIPTION

The program consisted of thirty four invited papers and two round table discussions, divided into seven sessions. The quality of the material presented well reflected the experience and expertise of the authors.

The opening session consisted of presentations by very senior members of the NATO space sciences and military communities. A broad overview was presented which served as an excellent introduction to the more detailed discussions.

Space systems and their applications had not been reviewed for a number of years by AGARD. The rapid progress that has taken place in this field and the increasing role played by space systems in maintaining and supporting military effectiveness was clearly evidenced in the range and depth of the subjects discussed in the sessions which followed. The symposium made a timely contribution by stressing the current desirability of more intensive application of space systems to military operations.

TECHNICAL EVALUATION

Session I – Overview **Chairman: Dr M.T.Weiss**

This session provided a useful framework for the subsequent discussions. The speakers characterized the range of current and potential applications of space systems and provided a perspective on the past and a forecast of future trends.

Dr Mark described the evolution of space capabilities, the importance of military space to the maintenance of peace and the need for joint effort among the NATO nations to maximize progress in current and future developments.

General Randolph reviewed the currently operational US military space systems and gave examples of their effectiveness in crises situations. He covered the range of capabilities available and described systems currently under development to meet future needs. He suggested that cooperative efforts among the NATO countries including the US, would be of great value to the tactical community.

Mr Gremke continued this theme by describing space system applications in the NATO theater. He indicated how space systems contribute to countering the threat to NATO forces and pointed out that the full exploitation of space assets is a learning process which is not yet complete.

General Craig provided useful insights into the application of space systems to tactical aircraft. A particular point was made that the proper design of terminals for tactical aircraft applications is of great significance.

The interaction of space systems capabilities and NATO's naval needs was the subject of Mr Nahra's talk. Among the points covered were the problems involved in combining forces of the various nations and in clearly distinguishing hostile and friendly forces.

Sessions II & III — Communications

These sessions brought into focus the vigorous activity in space communication systems throughout the NATO community. Both current applications and on-going developments were addressed. Some of the major issues discussed included the need for overall architectural planning, the importance of internetting and interoperability and of suitably designed terrestrial stations to optimize system utility.

Session II   Chairman: Mr D.Pichoud

Colonel Gibson described current and prospective US systems including their utility, the threats to which they must respond and prospective upgrades. The possibilities for internetting among the various space assets and with ground networks were discussed.

Mr Sonderegger provided a perspective from a broad architectural point of view, showing the possibilities for fitting both current and prospective systems into an overall framework. Problems of network control and management were cited.

Dr McElroy characterized EHF systems for space applications including the current and prospective state of the art in components, the applicable types of signal structures and the advantages which this frequency regime offers to military users.

Mr Du Chene's paper covered advanced developments for satellite communication as applied in the Syracuse system. The use of spread spectrum in the X band frequency regime was described together with the techniques for synchronization and the parameters of both fixed and mobile ground terminals.

The problem of orbit selection is pertinent to the various NATO nations whose territory extends to high latitudes. An analysis and evaluation of alternatives was presented by General Collins. The advantages of the twelve hour elliptical orbit for high latitude application include coverage, ease of doppler correction, and lower orbital energy requirements.

Session III   Chairman: Mr B.Atkinson

An overview of communication satellite activity in the United Kingdom was presented by Mr Atkinson. The discussion included description of developmental activities, testing facilities, and the various aspects of terminal equipment design important to the users. The advantages of interaction between the military and civil systems were pointed out.

Mr Tozer described the SKYNET 4 development and the details of the communication payloads functional characteristics. A description of potential advances for the next generation of SKYNET satellites was presented.

Dr Madams reviewed the communication satellite field from the viewpoint of Royal Navy requirements. A systematic presentation of requirements in matrix form was shown and a discussion of internetting as a means of enhanced survivability was presented.

Further discussion of terminal issues was furnished in a paper by Mr Law. Various types of terminals for different classes of users were described together with the variations and characteristics necessary for different classes of services.

Session IV — Navigation   Chairman: Ir. H.A.T.Timmers

Discussion of space based navigation systems was initiated by Colonel Jones with an overview discussion of the GPS/Navstar program. A description was provided of the current configuration and the plans for providing a full

constellation within the next few years. A variety of user equipments are under development and accuracy demonstrations have been accomplished for a variety of host vehicles including aircraft, ships, and land vehicles.

Mr Kruh described the means of building up a GPS constellation, the orbital configuration necessary for achieving global coverage and the geometric issues associated with maintenance of accuracy. The 18 satellite final configuration will provide better than 99% coverage globally.

The techniques for system tests which have been developed and are currently used to evaluate system performance were discussed by Dr Clifford. The precision land range as well as the arrangements for naval testing were described.

For tactical aircraft applications, a large number of variables must be controlled in order to meet accuracy requirements. Captain Barbee presented a description of these items together with an evaluation of the utility of the GPS system in controlling them. In summary, the GPS system simplifies control and supports enhanced effectiveness in a number of tactical applications.

Colonel Price reviewed the prospective utilization of Navstar by the NATO nations. Navstar development is perhaps unique in that nine NATO nations have participated in the GPS development and acquisition program. Furthermore, the intended use of Navstar by the various nations has supported improved commonality of navigation and mapping references among the nations.

Session V – Remote Sensing **Chairman: Dr R.W.MacPherson**

The discussion of current capabilities in remote sensing focused on meteorological satellite systems and their use. Other aspects of remote sensing were covered in Session VI.

The Defense Meteorological Satellite Program (DMSP) was presented in an overview by Colonel Curtis. The DMSP system provides worldwide strategic tactical and weather data to both fixed and mobile users. Future developments including enhanced sensing capabilities were described.

Colonel Rauscher described the manner in which the Air Force Global Weather Central merges data from DMSP as well as other weather satellites and terrestrial and oceanographic data. Data is processed every three hours and 48 hour forecasts are furnished. Tactical uses during various crisis were cited as well as support of planned military exercises.

The civilian weather satellite system and its relationship to military systems was presented by Dr Miller. The interaction between the American civilian systems and those of other nations was discussed and the importance of cooperation between all nations to achieve accurate weather forecasts was emphasized.

The importance of space systems in support of tactical military activities was illustrated graphically by Mr Pothecary and Captain Marsh in their discussion of the Falkland Island experience. The usefulness of remotely sensed data was apparent early on, and actual experience during crises led to changes in terrestrial equipment which further enhanced the utility of space systems. Practical experience is essential to optimizing utility.

The direct application of satellite weather data via video recording, the use of false color, and other human engineering techniques was discussed by Mr Boswell. The importance of techniques to enhance interpretability was clearly demonstrated.

Further emphasis on this subject was provided by Mr Weigand. The ability to adapt to varying circumstances and a variety of user requirements was noted. The flexibility of digital techniques is important. The need to receive frequent observations under some circumstances is characteristic of certain applications.

Session VI – Prospects for the Future **Chairman: Dr F.I.Diamond**

The papers in this session were oriented toward discussion of those space system elements which have demonstrated their importance but have not yet achieved full operational status or application.

General Abrahamson described the space shuttle, its objectives and accomplishments and noted that a variety of upper stages are available for various applications. The ability to retrieve payloads, to assemble large space structures in orbit and, generally, to greatly increase the flexibility of the management of orbiting assets were cited. Launch capability from either coast of the US will become available. Cooperative efforts with other NATO nations were described.

The most recent initiative in regard to shuttle upper stages was presented by Mr Clark. This is the shuttle-configured Centaur upper stage which will be capable of putting approximately 13,000 lb payloads into geosynchronous orbit using liquid oxygen and liquid hydrogen propellants.

In regard to expendable launch capability, a major development has been the Ariane booster, described by Mr Brachet. The Ariane booster is under the cognizance of the European Space Agency (ESA). It consists of a family of vehicles which has a present capability of placing 1500 kilograms into a synchronous equatorial transfer orbit. The Ariane family is an evolving system which incorporates planned growth leading to an eventual 4000 kilogram capability. The Ariane has

demonstrated its performance in practical use. An additional pad is being built to provide greater launch flexibility and capability for the largest version of Ariane currently planned.

Turning from launch vehicles to future developments for spacecraft, Mr Cochran described a series of measures involved in protecting future satellites systems from possible negation. Improvements in satellite autonomy, the use of cross linking between the various satellites and increased use of mobile terminals were discussed.

Remote sensing for applications other than weather forecasts was the subject of a discussion by Dr Velten. The European remote sensing satellite system, ERS1, is an application of imaging synthetic aperture radar to the measurement of geophysical properties including wind fields, ocean imagery and ice. The data will have both scientific and economic impact.

Another approach to the remote sensing of geophysical features and to mapping, is the SPOT remote sensing system described in a paper presented by Mr Brachet. The system is developed under the auspices of the French National Space Agency. It embodies a passive sensor operating in three visible bands and the near infra-red. Among its applications are evaluation of natural resources (renewable and mineral) as well as medium scale mapping.

Further discussion of advances in synthetic aperture radar technology was presented in the paper by Mr Schotter. An advanced processor is under development which has attributes which make it particularly suitable for data processing on board spacecraft.

Passive sensing was also the subject of the paper presented by Mr McCarthy on the application of infra-red techniques to detect objects of military interest. The use of space based sensors for this purpose provide advantages in coverage and timeliness of data.

Additional discussion of the technology and application of imaging synthetic aperture radar for earth resources research was presented in the paper by Mr Monson. The Shuttle imaging radar has been used to provide radar characterization of areas of the earth which had not been previously observed by this class of sensor. A movie of some of the observations was shown.

Session VII — Summary Chairman: Mr J.Statsinger

This session was structured to provide a recapitulation and summary of ideas and issues which developed from the papers and discussions of the preceding six sessions. Participants for this session included the chairmen of the preceding sessions, or their representatives, as well as Dr Allen Stubberud, Chief Scientist of the US Air Force. Some introductory remarks were presented by Mr Joseph Statsinger, vice chairman of the Program Committee.

The remarks and discussions during this session generally covered the major issues in regard to space system applications. Substantially all of the material from this session related to assessments, observations and recommendations with regard to the symposium topics. The executive summary, as well as the next section of this report covering these matters is, in substance, a recapitulation of Session VII.

ASSESSMENT

It was the general consensus that the symposium material was significant and relevant to the intent of the symposium and that the objectives of the meeting as outlined in Theme and Objectives were indeed met. In addition, the material presented went beyond the objectives of the meeting and provided important insights into additional aspects of space systems and their military applications.

With regard to the stated objectives of the meeting:

The papers and discussions presented indicated the importance of space systems in meeting current and future tactical needs in communication, navigation, surveillance, remote sensing and weather.

The characterization of space systems was accomplished with clarity and focused well on the relationships between the systems and their tactical application.

The advantages and limitations of space systems in tactical applications were reviewed in conjunction with the interaction of terrestrial resources and space resources.

A significant number of trends for the future and their importance in military applications were discussed.

OBSERVATIONS

It was noted that a number of areas would benefit by additional effort:

1. Communication between users and developers should be improved in order to:

(a) Establish better quantification of requirements

(b) Expose the developers more clearly to the exigencies of battlefield applications

(c) Identify the needs for flexibility

(d) Improve the familiarity of the using community with space system operational characteristics

2. Steps should be taken to improve interoperability among existing and planned systems in the NATO environment in order to enhance the utility of these broadly applicable systems.

3. The participation of the various NATO nations in cooperative development and application of space systems should be increased.

4. Alternative techniques for procurement and fielding of space systems should be developed and evaluated considering that small quantities and high unit costs will continue to be characteristic of these systems.

5. The impact of retrievable boosters on the development and application of space systems should be further studied.

6. The development of suitably configured ground assets should be pursued for the purpose of assuring maximum survivability and utility.

7. Areas should be identified where further advances in technology are desirable, in order to support future systems having greater capabilities than systems currently available.

8. Future activities should stress the importance of overall systems engineering and systems macro-architecture to assure that all of the elements involved in these complex systems are properly interfaced and that systems designs for individual space systems interact with each other for the overall greatest effectiveness in providing support to military operations.

RECOMMENDATIONS

1. Conduct a review of on-going and planned communication and navigation systems, both space and ground based. The review should focus on issues of interconnection and interoperability among all of these assets and the related architectural issues. The objectives should be to optimize the utility and survivability of the overall NATO capability.

2. Plan a symposium on space technology with the objective of defining initiatives which the NATO nations should pursue to increase the capability of future space systems.

3. Plan a symposium on the subject of space system macro-architecture. This should include questions of interoperability and survivability as major topics.

TACTICAL OPERATIONS AND SPACE APPLICATIONS

Major General T.L. CRAIG
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I am pleased to have the opportunity to talk to you about Tactical Operations and Space Applications as a single subject! As the Deputy Chief of Staff for Requirements for Tactical Air Command, my job is to obtain the necessary capabilities for all the fighter forces. The Tactical Air Forces include the United States Air Forces in Europe, Pacific Air Forces, and the Tactical Air Command as well as the Air Reserve Force. I am therefore strongly tied to the research, development and acquisition community because we depend on them to satisfy our requirements. I believe as you do, that when our potential adversaries are working hard to develop and field new advanced capabilities. We have no choice but to outwork them - both harder and smarter. It is particularly pleasing to see the nations of the NATO alliance holding hands and working smart to continue to make improvements in our collective capability.

I have taken as my subject "Tactical Applications of Space Operations". This is, perhaps, a "play on words" from the theme of this conference, but it best reflects where I think we are today in terms of marrying tactical and space operations. You could say my perspective is from the ground looking up, rather than being in space looking down.

Before talking about the high frontier, I want to remind us how frontiers have played in the past. The first battles were, in all likelihood, fought on the ground. Then came a second frontier as battles occurred on the seas. In the twentieth century, war truly became three dimensional as the airplane came on the scene. Now, we are talking about another new frontier -- space. It is certain to become increasingly important if the Soviets continue to make bold moves toward militarizing that medium. There is more to be said on that later, but the point to recognize here is that new frontiers don't replace old frontiers -- new ones just add to your responsibilities and make the eventualities more complex. This is not to say that new frontiers do not bring advantages and leverage as well, however.

It is with keeping one eye on the old frontiers that we in tactical operations can look at this new frontier which we call space. Thus in my remaining comments I'll try to develop what we see as tactical benefits from space operations in that light -- these include improvements in our ability to communicate, maintain surveillance, observe global weather, navigate, and obtain new frontier technology that can be applied to old frontier systems, such as computers, sensors, and so on. I will, however, stop short of speculating about war in space.

First, I'll talk about satellite communications. Since the first communications satellites were launched in the early 60s, the reliance on space communications has increased dramatically.

Satellite communications, or SATCOM for short, have a wide variety of applications, which include affording time sensitive, critical conversations among the leaders of the nations of the alliance, between allied field commanders and their assigned forces, and among national and allied forces for a range of command and control tasks associated with operating military forces.

SATCOM has both advantages and limitations -- First, the advantages: As we increase the number, the redundancy and the flexibility of the media available for our essential communications, we complicate the task for the ~~would-be~~ hostile radio electronic combat manager. SATCOM improves our ability to overcome intense electronic countermeasures which are certain to be employed by Warsaw Pact forces in their efforts to interrupt our command and control communications. SATCOM allows us to use terrain screening as an advantage in siting communications terminals. For example we can avoid hilltop sites for tactical communications nodes - we can site them behind the hill to reduce their vulnerability to enemy attack. SATCOM also is less vulnerable to enemy detection and exploitation because the communications path is overhead. Also, a SATCOM downlink footprint is wide enough to cover a large area and the problems associated with other long-haul communications media are avoided.

SATCOM brings us closer toward having the high levels of jam-resistance communications with the capacity required to support the exchange of data between automated command and control facilities and, in the future, weapon systems.

Unfortunately, SATCOM also has limitations. These include a current technology limitation which precludes us from developing an adequate number of small, lightweight, high performance SATCOM terminals to support all of our tactical requirements -- at a reasonable cost. Super High Frequency, or SHF SATCOM techniques give us either fairly large capacity, or a fair degree of anti-jam performance -- but not both at the same time. Today, we are developing a new Extremely High Frequency, or EHF satellite program -- called MILSTAR, which is heavily oriented toward providing a dependable, enduring SATCOM system, but realizing the promise of MILSTAR from a tactical perspective is still many years away. Satellite communications are an important element in our array of tactical communications resources. We want to do even more with SATCOM as hardware

begins to reflect tactical battlefield requirements. We should not reasonably expect, however, any sort of major revolution in connectivity for tactical command and control. In my view, we need to keep and improve every means available to us.

Since the first weather satellite was launched in 1962, their use has become commonplace -- we now take for granted the daily reporting of weather on television and are no longer awed by satellite pictures of today's weather for North America or Europe. The simple fact that this information has become commonplace -- and is available internationally attests to its usefulness. Our allied and national military forces also use weather satellite information on a daily basis.

Another important capability, the new search and rescue satellites, or SARSAT, were developed to aid in detecting and reporting distress calls from ships and aircraft -- anywhere on earth. This has dramatically improved the capabilities of national and international search and rescue organizations to respond more quickly and locate more accurately ships and aircraft that are in distress. You know what that means to the people involved.

We are looking forward to the improved navigation systems which space will provide. The use of space-based navigation systems promises to provide the Tactical Air Forces not only with more accurate and reliable information on how to navigate from point A to point B, but we expect it will also enhance our worldwide, all-weather, day/night combat ability. The NAVSTAR Global Positioning System, or GPS as we refer to it, is the best example of this type of space-based capability. Capt. Mike Barbee from my Armament and Avionics Requirements Division will talk later to you on GPS. From my perspective I think GPS will contribute significantly to the fighter pilot who has the tough job of destroying well-defended targets deep in enemy territory where pin-point accuracy is required -- and, at the same time, GPS will help him stay alive. Regardless of what capabilities we might build into future space systems, nothing will change the requirement of having to deal with targets on the ground. Let me cite an example of where technology in the past has made the right kind of contribution in dealing with a very "earthy" problem.

During the Vietnam War, we were tasked to destroy a bridge near Hanoi - the Thanh Hoa bridge. We expanded 873 sorties with no significant damage to the bridge -- and suffered 11 combat losses in the attempt. When laser guided bombs became available, we were able to destroy the bridge in one day with only eight sorties -- and no losses.

With GPS integrated into our fighter aircraft, we will substantially improve the navigational accuracy of the weapon system, and achieve those same kind of results at much less cost. A "smart" aircraft which can deliver standard conventional munitions accurately is considerably more economical than trying to make all of your munitions smart enough to achieve a kill against targets. In other words, smart airplanes and dumb munitions are a lot cheaper than inaccurate aircraft systems married to smart munitions. We will still have a need for smart weapons for particular targets, but this capability allows us to acquire a more efficient and complementary mix -- and save taxpayer money. In short, GPS will give allied tactical air forces a significant improvement in their operational effectiveness.

I want to turn now to what I'll refer to as "new frontier" technology. By this, I mean those technologies which have been and are still being developed to support our efforts in space. There are many examples we are all familiar with. When President John F. Kennedy announced the United States would undertake a program to put a man on the moon, resources were committed to the research and development efforts that would provide the capability to reach that goal. The technologies that emerged as a result of that and other research and development efforts are now commonplace. The hand-held calculators of today are now more powerful than the first computer that had to be housed in a large building. Many of you in the audience are wearing digital alarm watches -- I know that because I occasionally hear them beeping. Some of you may have computers in your offices -- or even at home. Over the past 25 years, we have witnessed an explosion in computer technology with processing speeds and storage capacities that are difficult to comprehend.

In the Tactical Air Forces, the on-board computers in aircraft such as our F-15s, F-16s, and E-3A AWACS are becoming increasingly more sophisticated. We are also using computers daily in handling our ground tasks. We are currently in the process of placing small computers at operational units to aid in routine tasks such as mission planning. These capabilities exist today largely because of the "new frontier" technology research and development efforts that were undertaken in the 1960s and 70s as well as that which is ongoing today. Programs to develop very high speed integrated circuits, of VHSIC, will push computer processing speeds beyond 30 million operations per second, will reduce component size and power consumption, while at the same time dramatically improving the reliability of those components.

We are working closely with the research and development communities to continue to define those potential applications of "new frontier" technology that will further improve the combat effectiveness of our tactical air forces. We are particularly interested in those improvements which may reduce investment, operating, and support costs. Many of the "new frontier" technology developments stand to do that -- and I think creative application to our existing and future requirements and their solutions will truly be one of the largest benefits the tactical forces can gain from our space efforts.

Now, I would like to go back to my earlier reference to "new frontiers" and the point that new frontiers don't replace old frontiers -- the new ones just add to responsibilities and make the solutions more complex.

For example, as with the other three frontiers, there is competition for the advantage in the space frontier. Each year, as you well know, the Soviet launch four to five times as many spacecraft as we do and the military use of space dominate the Soviet Space Program. This is no surprise since the space frontier offers significant military leverage if exploited. Let me digress for a moment to talk about how their use of space affects us.

First, the Soviets have fielded a number of space based sensors which give them significant information about our operations. For example, such a concept as dispersing airplanes is probably an idea for the past. Therefore, if our airplanes are to survive when they are on the ground, it is more likely to result from the protection offered by hardened shelters than by trying to relocate them. And second, because of the militant approach with the Soviets appear to have taken in their space grogram, it makes us have to remain very timid about building our combat capability upon "space only" critical nodes. Its akin to the argument about manual operations versus computer operations; what do you do when the computer breaks down? If you are in business, the answer to that question has one set of implications; if you are at war, the implications are altogether different and significantly more grave. Likewise, placing all of our eggs in the space basket in the face of the Soviet's potential for breaking those eggs is simply a step which I could not recommend at this time. We are however developing an anti satellite weapon so that we will have a deterrent to the Soviet space based threat.

The ASAT Missile, about 18 feet long, will be carried by F-15 fighters. Thus we come full circle. A weapon is launched from an old frontier to defend the new frontier and the capabilities of the new frontier make our old ones better. As I stated earlier, the old frontiers don't go away - they just get more complicated.

As we have seen, there are obvious benefits to be gained by tactical air forces from the use of the space frontier - and that does not necessarily mean manned space forces. The unparalleled increases in our capabilities to communicate, observe global weather, support search and rescue, maintain surveillance, navigate precisely, and develop new technology have, indeed, been impressive.

But, I cannot emphasize too strongly -- the need to integrate these space-related capabilities with those "old frontier" capabilities. This must be done so that those things that are done most effectively on land -- are done on land. Similarly, those things that are done most effectively at sea, or in the air, or in space are done in those "frontiers". My experience to date shows that tactical users and space developers need to do a better job of completing the architecture, hardware, and infra-structure which turns a new capability into an effective weapon or weapons support system. We are working hard in that regard, but we still have a long way to go and much to learn.

From a tactical standpoint the most challenging aspect of seeing a new frontier develop is to ensure space information and services remains compatible with existing frontiers. That is what we have had to learn to do successively as we moved from land - to the sea - and into the air in the past. Similarly, it is critical that we as nations of the alliance stand shouder-to-shoulder -- so that our forces can INTEROPERATE effectively in the future just as we have worked hard to have them do that today.

Another challenge, and this one will not be easy to meet, is to resolve relative priorities so that money spent for defense will yield the most results. A new frontier does not mean there is more money available, it just means there is more competition for programs in the budget. The measure of merit must remain one of determining the contribution expected of new systems.

As members of the defensive forces of NATO, we are ultimately responsible to our citizens for the manner in which we spend their tax monies. With our every effort, we must remain aware of cost effectiveness -- of how we can do the job right, -- and keep COSTS to a minimum.

The ability of our combined forces to operate freely in space is essential. While we lag in the military applications of space, be assured, the Soviets will be, and are, actively pursuing space as the high ground. They are working hard at it, and the military use of space dominates their efforts.

Their primary goal is to achieve a dominant role in space. This we should not allow.

We have accomplished much to date. But we have much left to do to integrate ground, sea, air, and space into complementary mediums which best serve our common goal-world peace.

Research and development is needed to tell us how best to go about that task.

I applaud and support your efforts to promote research and development for defense of the NATO community and wish you great success in this conference.

The discussion which followed this presentation appears in classified publication CP 344 (Supplement)

US MILSATCOM – PRESENT AND FUTURE

by

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OVERVIEW

Military communications satellites today play a vital role in the successful operation of U. S. worldwide command and control systems. They support strategic forces with nuclear capabilities, as well as tactical air, ground, and fleet operations, the intelligence community, and defense wideband communications systems. With application of new and evolving technologies, future communications satellites are expected to provide even more improved communications services and performance.

To be consistent with the theme of the symposium on "Space Systems Applications to Tactical Operations," conducted in October 1983, the communications requirements of tactical users of U. S. Military Satellite Communications (MILSATCOM) systems are discussed first in this paper, and present MILSATCOM systems are then briefly described. In recognition of known threats to satellite communications systems, the deficiencies in tactical military satellite communications are outlined. Then developing and planned MILSATCOM systems and the benefits of increased survivability expected to be achieved by interoperability and internetting are discussed. Finally, evolving technologies, especially in the new communications band extremely high frequency (EHF), and their potential payoffs are described.

REQUIREMENTS FOR TACTICAL SATELLITE COMMUNICATIONS

The Conventional Forces of the Air Force, Army, Navy, and Marine Corps engage in land, sea, and tactical air operations ranging from single service crisis missions to joint task force operations. These forces are classified as tactical and thus their satellite communications requirements are emphasized in this paper. The requirements for the tactical missions include:

- Communications among forces within and between theaters
- Ship-to-shore/ship-to-ship communications
- Theater trunking for ground mobile forces (GMF)
- Communications support to allies.

In each case, the communications may take the form of voice, facsimile, or data with the data rates as indicated. Typical data rates are:

Tactical Single Channel	-	75 to 2400 bps
Manpack	-	75, 300, 2400 bps
Fleet Operations	-	75 to 4 X 2400 bps
Air Operations	-	75 to 2400 bps
Theater Trunking for GMF	-	75 to 2400 bps, 16, 32, or 48 kbps

In considering future tactical needs, conventional forces require jam resistant, secure, and reliable communications with a low probability of intercept and with high electronic survivability among a large number of mobile users.

CURRENT MILSATCOM SYSTEMS

FLTSATCOM

The Fleet Satellite Communications (FLTSATCOM) system provides worldwide, high priority communications between naval aircraft, ships, submarines, ground stations, the Strategic Air Command, and the National Command Networks. Each satellite has 23 communications channels in the ultra high frequency (UHF) band. Ten of the channels are used principally by the Navy for tactical communications (shown by the hatched area in Figure 1) among its worldwide land, sea, and air forces, while 12 other channels aboard each spacecraft are used principally by the Air Force as part of its satellite system for command control of nuclear forces. A single 500 kHz channel is allotted to the National Command Authority. The fleet broadcast channel on each satellite has jam resistance provided by its super high frequency (SHF) pseudo-noise uplink from Naval Communications Stations.

Naval forces are provided with a variety of tactical communications services. The fleet broadcast channel (Channel 1) is a one-way shore-to-ship channel with no report back capability. This 25 kHz channel supports a time-division multiplexed broadcast at 1200 bps. Channels 2 through 10 all have bandwidths of 25 kHz and provide flexible selections of communications services. The Air Force portion of FLTSATCOM consists of twelve 5 kHz channels, capable of providing 75 bps teletype signals. Some of these channels can also support other narrowband communications.

Army tactical communications are supported, on an as required basis, within the 500 kHz channel, within the FLTSATCOM 25 kHz channels, or within the AFSATCOM 5 kHz channels.

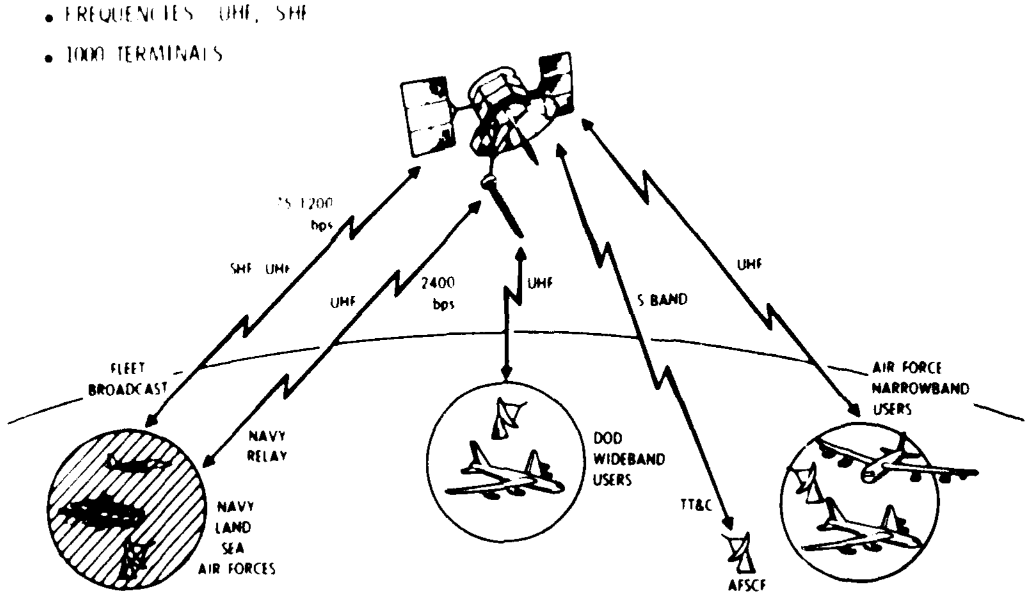

Figure 1. FLTSATCOM

AFSATCOM

The Air Force Satellite Communications (AFSATCOM) system is designed primarily to provide command, control, and communications capability to designated high priority users for Emergency Action Message (EAM) dissemination, Joint Chiefs of Staff/Commanders-in-Chief internetting, force direction, and force report-back. AFSATCOM is a very low capacity system consisting of narrowband dedicated channels designed for teletype use (75 bps). As such, the AFSATCOM is limited in capability to provide tactical communications services. Figure 2 schematically depicts the major communications links of the system.

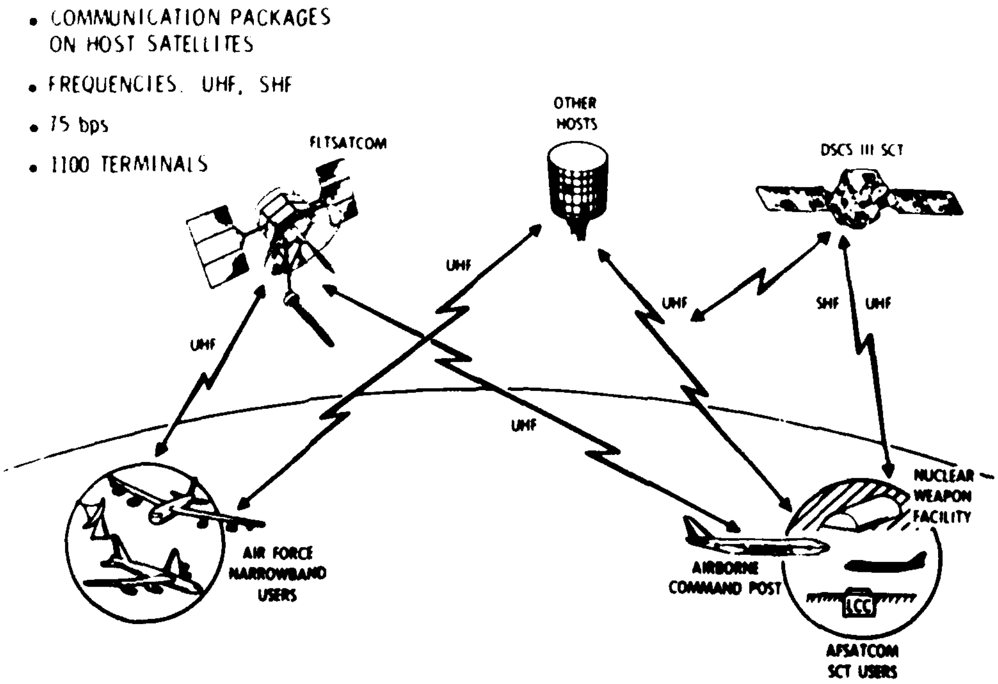

Figure 2. AFSATCOM

The space segment of the AFSATCOM system consists of four types of transponders carried on different host satellites, including FLTSATCOM and DSCS III, which is described in a following section. Each of the four synchronous FLTSATCOM satellites will provide the Air Force one 500 kHz and twelve 5 kHz channels. The transponder packages on other host satellites provide a backup EAM dissemination capability to increase the physical survivability of the AFSATCOM system. As a part of AFSATCOM, a Single Channel Transponder (SCT) payload is integrated into DSCS III for secure and reliable dissemination of the EAM and Single Integrated Operational Plan (SIOP) communications from worldwide command post ground stations and aircraft. The SCT operates at either SHF or UHF, relaying command and control communications from ground and airborne command posts to the SIOP forces.

DSCS II

The Defense Satellite Communications System Phase II (DSCS II) provides tactical communications to service naval ship to shore and GMF requirements, as shown by the hatched areas in Figure 3. Naval communications are supported only for capital ships. GMF communications are in theater tactical trunking and point to point multichannel voice/fax/data.

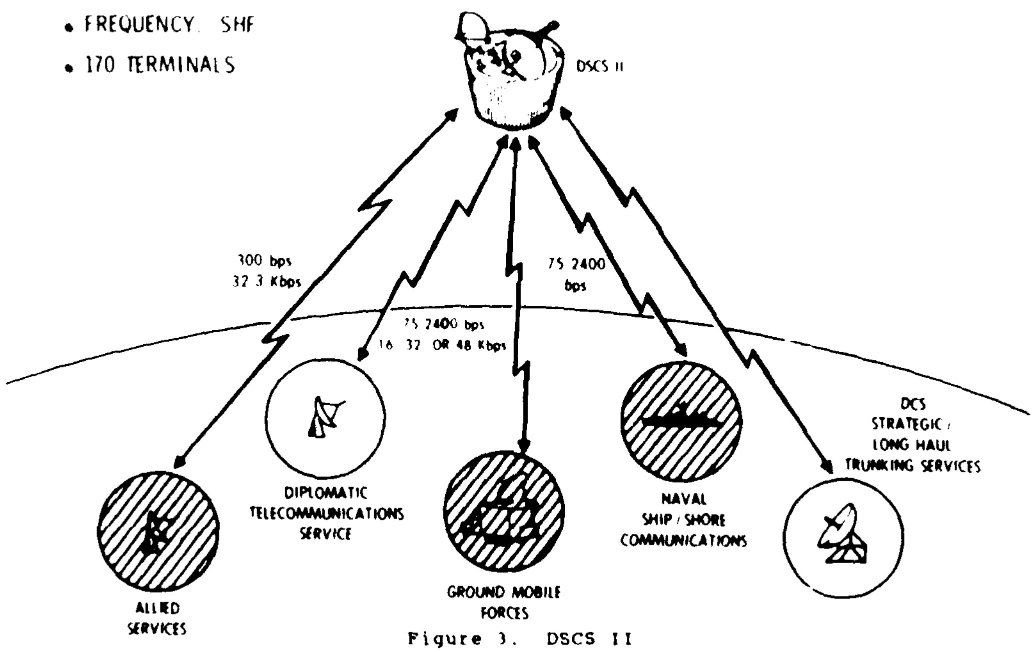

Figure 3. DSCS II

The DSCS II has been designed to provide long-distance wideband communications between major military locations. With two narrowbeam antennas and an earth coverage antenna, a wide variety of wideband trunking terminals can be served. These include Defense Communications System (DCS) trunking services, naval ship to shore communications terminals, GMF, diplomatic telecommunications services, and Allied/NATO services. There are four channels, with bandwidths of 125, 50, 185, and 50 MHz, with interconnections between narrowbeam antennas and the earth coverage antenna, which allow adaptation of services to particular requirements. DSCS II provides 1300 two way voice circuits or approximately 100 Mbps.

DSCS III

A gimballed dish antenna has been incorporated into DSCS III specifically to support GMF operations. Ships at sea will also use the multiple beam antennas and beam forming networks. Both will enjoy more tailored SATCOM services.

Significant features of DSCS III (shown in Figure 4) are the multiple beams, diverse beam forming capability, and the SCT. The receive multiple beam antenna (MBA) contains 61 beams which can provide diverse beam patterns through a beam forming network, providing increased uplink antijam (AJ) capability. The transmit MBA contains 19 spot beams. When all beams are enabled, the result is earth coverage. SHF transmit and receive horns provide an additional earth coverage pattern. DSCS III has six channels with bandwidths of 85, 50, and 60 MHz.

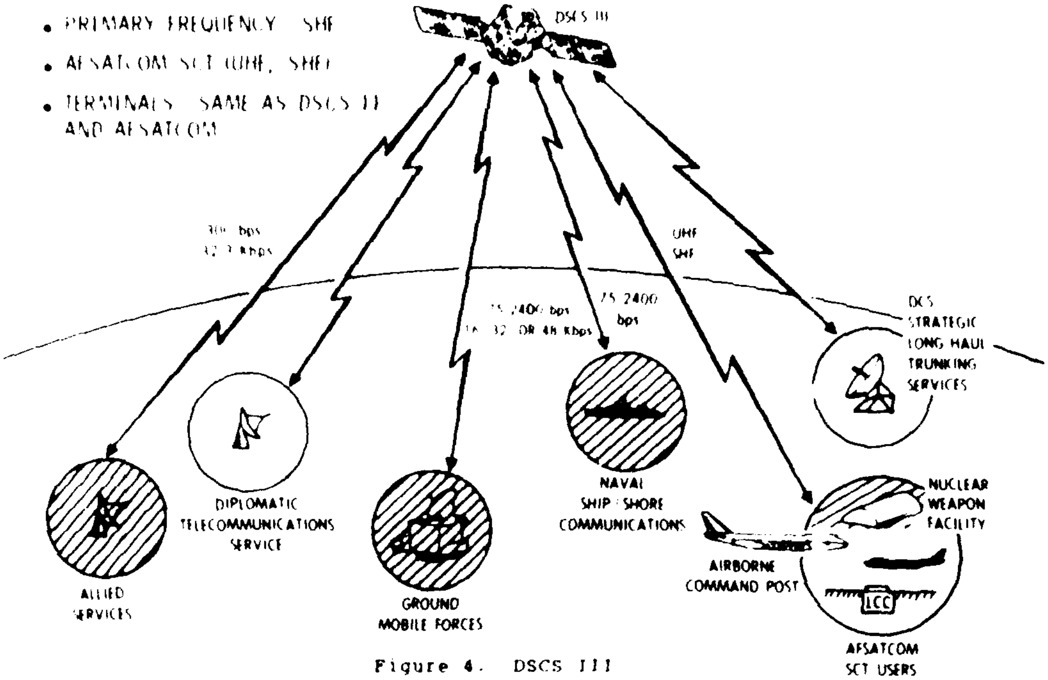

Figure 4. DSCS III

THREATS TO SATELLITE COMMUNICATIONS SYSTEMS

Figure 5 displays "why we need to think survivability," especially in time of crisis. As depicted in this figure, U. S. communications satellite systems are susceptible to a significant number of threats. In the case of enemy jamming, several possibilities exist for countering this enemy mission. For satellite communications links, the use of EHF, on board processing, and adaptive antennas are especially important for protecting small, mobile terminals. These techniques tend to neutralize the power advantage of large jammers. Also, the higher frequencies are less susceptible to propagation disruption by nuclear events.

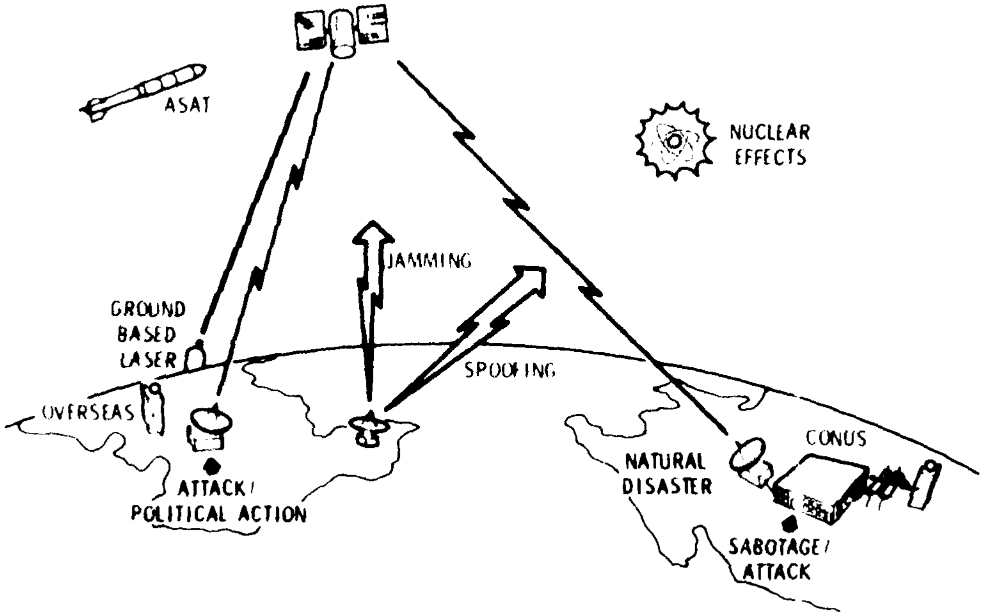

Figure 5. Threats to Satellite Communications Systems

There are a number of strategies to counter the effect of a physical attack on ground or space segments. Such a threat can vary from local sabotage to massive destruction, depending on the level of conflict. However, the most cost-effective method of assuring a secure communications service is to use network redundancy to the maximum extent possible. An approach currently in development stages is discussed in a proceeding section of this paper.

DEFICIENCIES IN TACTICAL MILSATCOM SERVICES

As discussed, today's MILSATCOM systems serve many important military functions, and they have evolved to meet specific user needs for improved communications. FLTSATCOM provides limited tactical communications services to military users. AFSATCOM satellites primarily serve the Nuclear Capable Forces. DSCS II and DSCS III are wideband repeaters which operate mostly with large terminals at SHF. These current MILSATCOM systems are not capable of satisfying all tactical communications requirements.

Some MILSATCOM deficiencies are listed below:

- o Insufficient capacity
- o Low jam resistance
- o High vulnerability to interception
- o Poor physical survivabilty of satellites and terminals
- o Insufficient service duration

To reduce these deficiencies to the level of acceptability, new military communications satellites are being planned. MILSTAR, scheduled to be deployed in the late 1980s, is the next generation satellite program designed to service both the strategic and tactical forces. MILSTAR will provide more reliable and effective communications through the use of EHF and advanced techniques, which will defeat potential enemy jamming. Also, an advanced future DSCS with both SHF and EHF channels is being planned, to increase communications capability and jam resistance for wideband, long haul, and inter intra theater relay services.

FUTURE MILSATCOM SYSTEMS

MILSTAR SYSTEM

The MILSTAR system is designed to be reliable and operational for both tactical and strategic forces worldwide during all levels of conflict. Equipped with jam resistant EHF transponders, on-board signals processing, orbital crosslinks, and nuclear hardened electronics, MILSTAR satellites will be a strongly protected U. S. satellite system against any jamming or physical attack. MILSTAR ground stations and user terminals will also be more mobile and survivable than existing systems. A schematic of the system is shown in Figure 6.

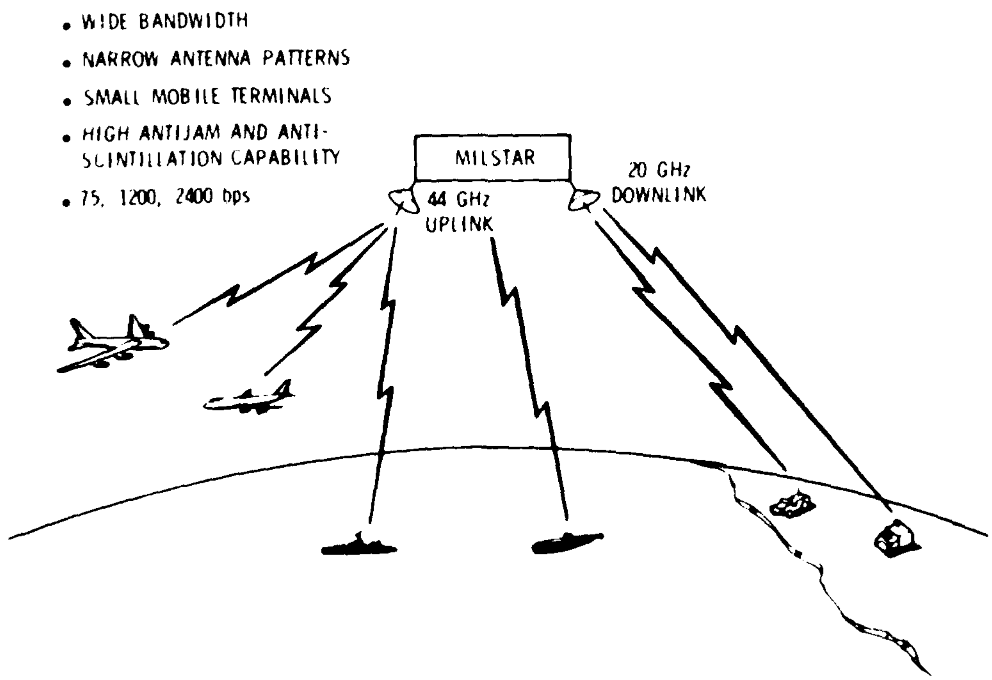

Figure 6. MILSTAR System

The MILSTAR system's high AJ capability is a result of employing the higher EHF band 44 GHz uplink and 20 GHz downlink. The greater bandwidth available at EHF permits the use of spread spectrum and frequency hopping techniques across a 2 GHz range. In contrast, AFSAT is limited to a very narrowband hopping range. Typical MILSTAR data rates are 75, 1200, and 2400 bps.

FUTURE WIDEBAND SERVICE

As stated, planning has begun on a future DSCS with SHF and EHF channelization to provide wideband services, including tactical communications in the 1990s (Figure 7). The future wideband satellite will provide long haul support communications for user commmunities, such as the Defense Switched Network (Autovon, Autosevocom, Autodin, etc.) and the GMF. Data rates as high as 20 Mbps are anticipated, but lower data rates 75-2400 bps, 16 kbps, or 32 kbps will also be accommodated, serving users within and between theaters.

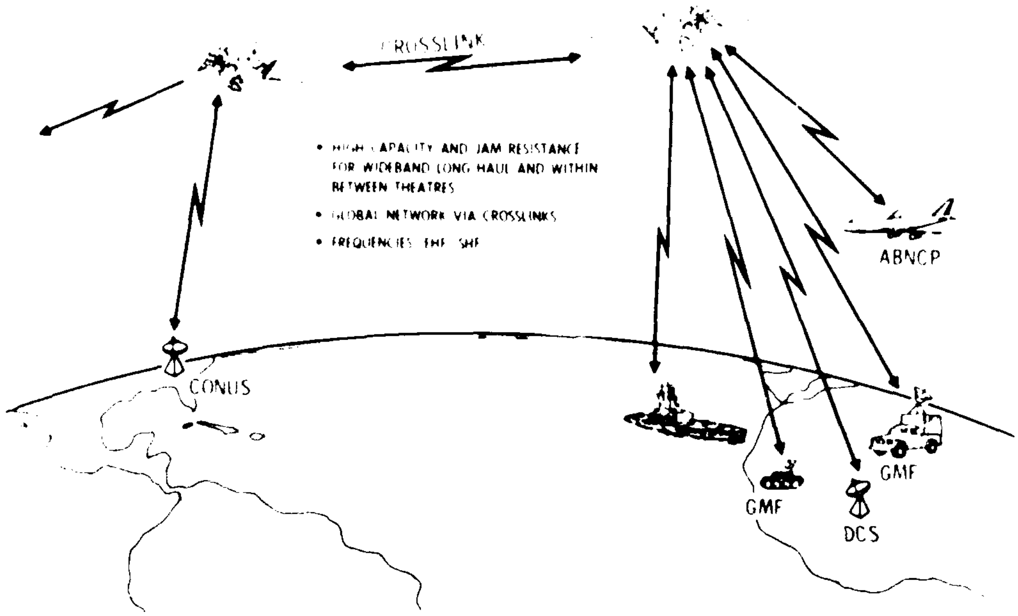

Figure 7. Future Wideband Service

Resistance to jamming may be achieved by the MILSTAR EHF technologies such as adaptive antennas, frequency hopping spread spectrum, and on-board processing. Narrow antenna beams and spread spectrum may also be used to provide a low probability of intercept. Cross banding of GMF multiple-channel users may be desired. In addition, the system may establish global network coverage via wideband crosslinks with multiple downlinks to the continental United States (CONUS).

SURVIVABLE INTEROPERABLE NETWORKS

INCREASED SURVIVABILITY IN INTERNETTING

At Air Force Systems Command Space Division, Los Angeles Air Force Station, personnel on several satellite programs are exploring EHF to provide survivable links. With the EHF band, common waveform format, and other common link standards, these satellite programs can be internetted to allow communications; tracking, telemetry, and command (TT&C); and mission data to be routed through a variety of systems. In this concept, data are data. System survivability is increased by having interoperability. Communications terminals and TT&C terminals provide backup systems for each other. Also, use of various terrestrial links to augment the system can ensure that the internetted system is even more survivable.

FUTURE SATELLITE SYSTEMS

Figure 8 is a summary schematic of the discussions in this paper: internetted space and terrestrial systems for survivability.

Future military satellite systems are expected to have interoperability wherever possible in order to provide alternate links, thus providing connectivity and survivability.

U. S. national policy requires that the capability for command, control, and communications endure a protracted nuclear war. This policy demands a resilient network that will sustain significant damage, continue to function at a reduced level, and permit connectivity to be restored.

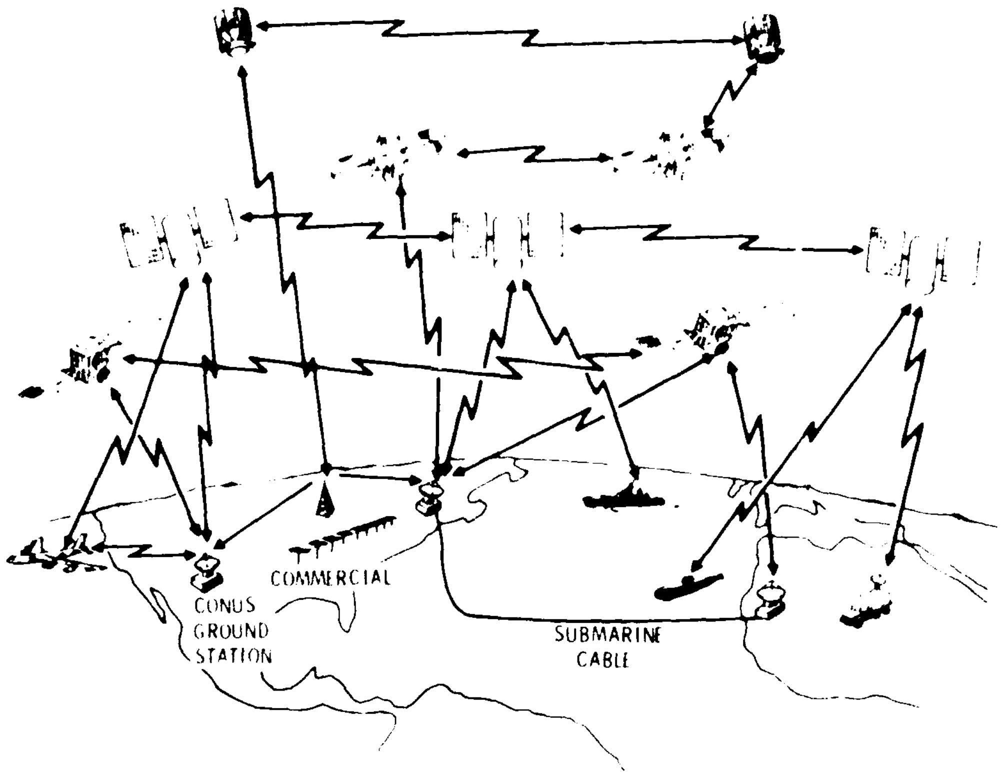

Figure 8. Future Satellite Systems

Military space planning must point toward a broad network that embraces numerous military satellite and terrestrial nodes and can be interconnected with commercial systems where warranted. The network must provide service to various fixed and mobile users and should be flexible enough to operate through all the levels of conflict. Crosslinks are also important to reduce dependence on fixed ground stations.

USE OF TECHNOLOGIES

Development and implementation of an EHF system such as MILSTAR are an unequaled technology challenge. Fortunately, significant and extensive developmental experience has been gained through the use of LES 8/9 spacecraft (Lincoln Experimental Satellite), demonstrating space qualified EHF, on board processing, UHF EHF crossbanding and satellite to satellite crosslinking.

Major development efforts include:

- Common waveform design, providing interoperability and enhanced survivability
- Advanced adaptive antennas, providing uplink nulling and steerable downlinks
- On board processing for increased capacity and/or antijam
- Solid state devices for increased power amplifier reliability
- Satellite-to-satellite crosslink technology (60 GHz and Lasercom)
- Autonomous spacecraft operation
- "Low cost" small EHF terminals (a technological challenge)

Potential payoffs resulting from the use of these technologies are listed below and indicate that the requirements for tactical satellite communications will be satisfied in the future:

- Enhanced survivability
- Antijam, increased capacity, frequency reuse
- Multiple access, antijam, antiscintillation, crosslinks
- Reliability, endurance, cost
- Protection from ground based jammer threats
- High data rate capability, low probability of intercept, antijam

SUMMARY/MILSATCOM ARCHITECTURE

Figure 9 is a summary review chart of future projections with respect to satellite communications in support of tactical users. As stated, current U. S. systems evolved from specific user needs. DSCS provides communications service for fixed and transportable terminals, and extends mobile service to a limited number of ships and

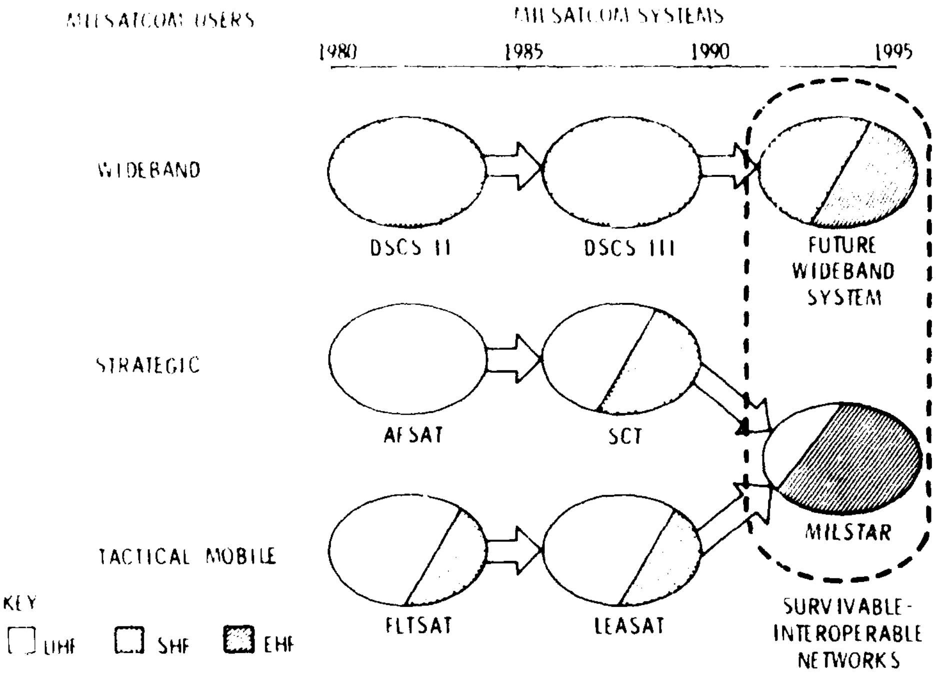

Figure 9. MILSATCOM Architecture Summary

aircraft. ASFSATCOM on the host satellites provides a channelized, low data rate service supporting nuclear capable forces, including bombers, missiles, submarines, and theater nuclear weapon systems. FLTSATCOM supplies a channelized service with a low data rate for tactical mobile units. It is used for Navy Fleet operations and the U. S. central command for contingency operations. LEASAT, the follow-on to FLTSAT, will primarily serve the Navy, plus some Air Force and ground forces mobile users. The LEASAT user population is basically the same as that for FLTSAT.

In the 1990s, MILSTAR with UHF/EHF will be the communications satellite for tactical users and will serve as the focal point for development and transition to the internetted system. To achieve the goals of this MILSATCOM architecture, an evolutionary approach is planned.

The discussion which followed this presentation appears in classified publication CP344 (Supplement)

INTEGRATED SUPPORT OF TACTICAL OPERATIONS BY SATELLITE COMMUNICATIONS

by
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SUMMARY

In our work in cooperation with the U.S. military departments and agencies on the development of a Worldwide Digital System Architecture (WWDSA) for the U.S. Department of Defense (DoD), we established 14 key features for the WWDSA goal architecture. One of those key features, all of which have been approved by the U.S. Joint Chiefs of Staff (JCS) for planning purposes, is the expanded and integrated use of satellite communications in the support of both strategic and tactical defense missions. Under the WWDSA concept, satellite connectivity will be available on an as needed and near instantaneous basis through the use of Demand Assignment Multiple Access (DAMA) without overtaxing satellite capacity. Satellite communications will be used not to replace but to complement the other means of connectivity; in some cases satellite communications will be used only when no other means of suitable connectivity are available as for restoral of damaged terrestrial links or for provision of temporary video circuits. A large number of small satellite earth terminals, with an effective integrated satellite/terrestrial transmission control system, would allow satellite communications to be truly integrated with other communications media to provide increased survivability and more effective support of tactical, strategic and defense-wide operations.

INTRODUCTION

The Defense Communications Agency (DCA) was tasked by the U.S. Office of the Secretary of Defense (OSD) to take the lead in the development of a Worldwide Digital System Architecture (WWDSA) to serve as an umbrella for all DoD telecommunications architectures and to provide guidelines for increasing the survivability and interoperability of DoD telecommunications systems. The WWDSA was developed by DCA and the WWDSA Working Group; the Working Group was made up of representatives from the Military Departments and Department of Defense (DoD) Agencies. WWDSA applies to virtually all geographically separated tactical, strategic, and defense-wide DoD telecommunications, and to both U.S. government-owned and leased communications facilities and services.

WWDSA can be described by the 14 key features shown in Figure 1 (see Reference 1). These key features have been approved for planning purposes by the U.S. Joint Chiefs of Staff (JCS). One of the features, WWDSA Feature L, specifies the expanded and integrated use of satellite communications (SATCOM), including the use of small satellite terminals and demand assignment multiple access (DAMA) at all switching nodes serving critical command and control users.

This paper describes how WWDSA Feature L can provide integrated satellite communications support of tactical operations. The paper represents the views of the author and not necessarily those of DCA or the Department of Defense.

FIGURE 1 -- WWDSA FEATURES

A -- Access to many sources of connectivity

B -- Ability to use many sources of connectivity intelligently

C -- Modularly expandible switches

D -- Interconnected voice and data networks

E -- Improved intra-network system control

F -- Tandem switching capability

G -- Multirate capability among circuit switches

H -- Enhanced 2.4 kbps secure voice survivability

I -- High quality 16 kbps secure voice

J -- Common proliferated key distribution system

K -- End-to-end encryption for classified data

L -- EXPANDED AND INTEGRATED USE OF SATELLITE COMMUNICATIONS

M -- Improved inter-network system control

N -- Use of common standards

COMMUNICATIONS SUPPORT OF TACTICAL OPERATIONS

All types of military operations require communications support that is responsive to changing requirements and as survivable as the persons or machines who use the communications (Reference 2). Communications in support of tactical operations, as compared to those in support of other types of military operations, require:

- Increased transportability
- More ruggedness
- Simpler operation
- Greater responsiveness
- Ability to operate in a difficult-to-predict and highly competitive frequency spectrum environment

Tactical communications do not ordinarily operate out of fixed sites as do defense-wide and many strategic communications. Most tactical communications equipment must be portable, mobile, or at least easily transportable because of the requirement to support military forces that do not operate out of permanent bases. Further, tactical communications facilities do not ordinarily provide the office environment that is available to other types of communications, so tactical communications equipment must be able to withstand severe weather and other environmental extremes. Tactical communications must be easy to set up, simple to operate, and capable of responding to a wide range of possible communications needs in the support of tactical operations (Reference 3). And because it is often not possible to predict very far in advance where tactical forces will be deployed, frequency spectrum management must be handled quite differently than for fixed communications systems.

Tactical communications are provided by a variety of transmission media including:

- o Strung-out wires and cables
- o Hand-held and vehicle-mounted microwave radios
- o Line-of-sight microwave relay towers
- o Tropospheric scatter links
- o Mobile and transportable high frequency radios
- o Transportable satellite communications terminals

Wires and cables are used where practical to provide some protection against interception and to conserve the radio frequency spectrum. Included in the category of cables are fiber optics, which is coming into use much more rapidly than had been expected. Microwave communications such as hand-held and vehicle-mounted radios have proven their value on the battlefield, although problems exist in the area of spectrum management. Line-of-sight (LOS) microwave relay towers extend the range of microwave communications, but they must be protected against physical damage. Tropospheric scatter links, which are less reliable than LOS and are more vulnerable to jamming, can join locations separated by 100 km and more. High frequency (HF) radios have been used to support tactical operations for years, and they are still useful even though they are bulky, difficult to secure, easy to jam, and they operate in an already crowded part of the frequency spectrum. Satellite communications are relatively new to the battlefield, but they have proven themselves to be quite useful for high quality, long haul communications. They are normally used for point-to-point communications over distances greater than 300 km.

EXPANDED AND INTEGRATED USE OF SATELLITE COMMUNICATIONS

Technological advances are allowing the introduction of satellite communications features that will increase the level of satellite communication's support to tactical operations (Reference 4). Among the new features are:

- o Operation at higher frequencies
  - better beam control
  - improved anti-jam capability
  - increased mobility
- o Digital equipment and operation
  - better power control
  - improved anti-jam capability
  - more flexibility
  - increased reliability
  - lower human resource requirements

Better beam control on new communications satellites allows service to smaller terminals and spacial discrimination against unwanted signals. Better beam control on satellite earth terminals provides higher gain for small antennas and allows spacial discrimination to filter out unwanted signals and to reduce the probability of intercept. An improved anti-jam capability is possible because the increased transponder and earth terminal throughput at higher frequencies allows higher protection through spread-spectrum techniques, adding to the improved rejection of jamming signals due to beam control. Increased mobility results from the smaller sizes of antennas and other equipment possible at the higher frequencies.

Digital equipment and operation make satellite on-board processors practical. Onboard processors, in turn, eliminate the problem of maintaining a delicate power balance, make beam control practical, and provide much better anti-jam protection. On-board processing greatly increases the flexibility of satellite operation, and makes practical a sophisticated form of demand assignment multiple access (DAMA). The use of DAMA will allow the resources of a satellite to be allocated more efficiently among occasional or intermittent users (Reference 5). The use of digital circuitry both in satellites and at earth terminals greatly enhances equipment reliability and, at the earth terminals, significantly reduces personnel and other O&M costs. These new features will substantially improve the ability of satellite communications to support the tactical mission.

The Ground Mobile Forces Satellite Communications Program (GMFSCP, Reference 6), which uses the newest version of the Defense Satellite Communications System (i.e. DSCS III, Reference 7) and MILSTAR (Reference 8), will facilitate the use of satellite communications to support tactical operations. The GMFSCP should provide a capability for small satellite terminals and at least limited demand assignment multiple access (DAMA). Next generation communications satellites, if they are to satisfy the WWDSA requirements, should provide an enhanced DAMA capability and highly integrated tactical operations support.

Operation at higher radio frequencies makes it practical for satellite earth terminals with antenna apertures as small as a square meter to be made available to key personnel at all times to help assure survivable connectivity for critical command and control.

DAMA, in combination with small satellite earth terminals, will make it possible for selected individual users to take their own terminals with them wherever they go and obtain satellite connectivity on an as-needed basis. DAMA is often thought of as providing circuits at bit-rates of 2.4, 16, or 32 kbps. Such bit-rate limitations are not adequate to satisfy WWDSA Feature L. WWDSA requires a new, enhanced DAMA that also can provide higher capacity circuits suitable for video and other wideband applications. Of course, wideband connectivity could be provided only under fairly favorable conditions. An enhanced DAMA will make it practical for small satellite terminals to be held in standby

at critical locations, and used only when necessary for wideband connectivity, or for restoral of terrestrial circuits. Video teleconferencing will be available at a moment's notice without prior circuit reservation. A disrupted terrestrial microwave circuit will be replaceable on a temporary basis by satellite.

A portion of a transponder's capacity will need to be allocated specifically as a pool for this type of multirate DAMA operation. For example, the capacity requirement might be established based on the capacity needed to support ten anti-jam protected 2.4 kbps circuits. The uplink capacity of satellite earth terminals with anti-jam protection would probably be limited to a single 2.4 kbps circuit. However, under non-jamming conditions, if the system is so designed, the same transponder capacity should be able to support several digroups (twenty-four 64 kbps channels per digroup), several video channels, or a mixture of the two. The pool capacity would not have to be sized to accommodate all prospective users simultaneously because, under the WWDSA concept, most locations would use satellite connectivity only when all other means of connectivity had been destroyed or were otherwise unavailable. When the pool capacity is insufficient to accommodate all users, the pool will be allocated among contending users on a priority basis.

The expanded and integrated use of satellite communications, as described by WWDSA Feature L (Reference 1), does not simply imply more point-to-point and DAMA communications. It implies a truly integrated use of satellite and terrestrial communications, operating under what we at DCA refer to as the "mix of media" philosophy (Reference 2). The mix of media philosophy will be expanded upon in the following section.

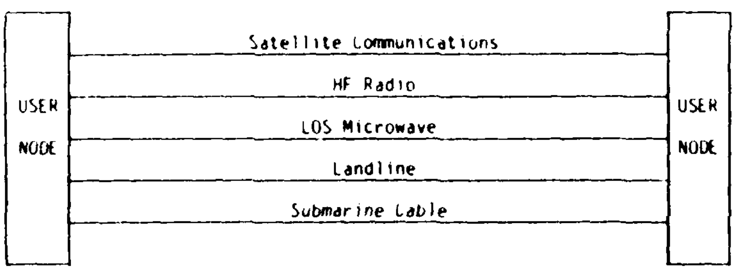
SURVIVABILITY CONSIDERATIONS

The main objective of a telecommunications system is to provide the connectivity for the transfer of information among two or more persons and/or machines. To satisfy military communications requirements, connectivity must continue to be available when needed even under direct attack, so long as any users exist who need the connectivity. The users normally do not care whether the connectivity is provided by satellite communications, by landlines, or by tin cans with a string -- so long as the connectivity exists when needed and is adequate to pass the necessary information. Military connectivity ideally should be absolutely survivable and should continue to survive throughout the full range of possible conflicts, from peacetime to nuclear war.

Of course there is no such thing as absolute survivability for any given communications link. But neither is there absolute survivability for any given communications user. Therefore the requirement is for absolute survivability of the connectivity between two or more users so long as more than one user continues to exist. If User A needs to maintain communications connectivity with User B, the need for A-to-B connectivity ceases to exist if either User A or User B is destroyed.

In order to achieve survivability, connectivity must be designed in such a way that it would cost the enemy forces more money to break the connectivity than it would cost the friendly forces to maintain it. Analysis has indicated (Reference 2) that the most practical approach to maintaining connectivity against attack is to utilize many different sources for that connectivity (see Figure 2).

FIGURE 2 -- "MIX OF MEDIA" PHILOSOPHY



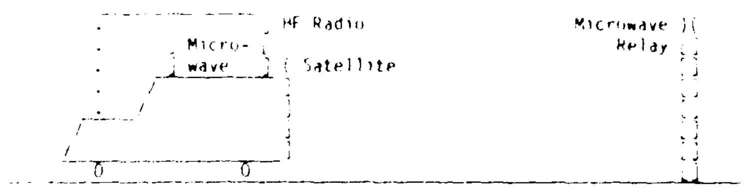
Satellite communications, especially with small earth terminals and operation at higher frequencies (i.e., EHF), are an important source of survivable connectivity for several reasons:

- Small earth terminals, when located among trees or boulders, can be more easily protected than large earth terminals, microwave relay towers, and tropospheric scatter antennas.
- Satellite communications do not require any intervening terrestrial relay points, and satellites carrying transponders are not likely to be physically attacked in a tactical war because such attack would more than likely raise the conflict to the strategic level.
- The emission from satellite uplinks at EHF and above can be confined to such a low level of power outside the main beam that interception of the uplink is unlikely, helping to protect the location of the satellite earth station from discovery and attack. Many other types of communications equipment tend to illuminate themselves, facilitating their discovery and increasing the probability of physical and electronic attack.

Tactical operations *already* use a "variety" of transmission media, but they do not necessarily use a "mix" of transmission media unless connectivity between any two locations can be provided by many different sources of connectivity. If some locations are served by wireline, some by LOS microwave, and others by portable HF radios, that does *not constitute a mix of media*. *A mix of media* implies a choice of transmission media available between any two specific locations at a given time. A choice of media provides more than one back-up transmission medium should the primary medium become disabled.

Consider the example illustrated by Figure 3, where a communications node is mounted on a motorized vehicle. The node could be served by a UHF radio, an HF radio, and a small satellite terminal with a one-meter dish. The communications node needs to survive only so long as the vehicle survives. Obviously, communications from the vehicle are more survivable with three different communications media than they would be with only one. Normally, the UHF radio would be used for line-of-sight communications, the HF radio would be used for communications beyond the range of the UHF radio, and the small satellite terminal would be used for communications beyond about 300 km. But there is no physical reason that the HF or the small satellite earth terminal could not be used to restore a critical circuit normally provided by line-of-sight communications. Such use would not be conventional, and normally would not be considered cost-effective, but it would allow vital connectivity to be maintained when it otherwise could not be.

FIGURE 3 -- "MIX OF MEDIA" EXAMPLE



INTEGRATED COMMUNICATIONS CONTROL

Perhaps one of the most difficult technical and administrative problems in providing truly integrated satellite and terrestrial communications to support tactical operations is the problem of integrated communications control. Some of the questions that must be answered on a moment-by-moment basis during a conflict are:

- o Which means of connectivity should be used for each application?
- o How are scarce assets of connectivity allocated when many important users are competing for the same assets?
- o How is the coordination handled between the local transmission node and all of the transmission nodes that are being dealt with in the selection of means of connectivity?
- o How is the connectivity selection for an entire theater coordinated, and how is the assignment of frequencies managed?

Today, addressal of the above questions is usually manual, and the decisions are often arbitrary. System control is difficult, with basically separate control systems for satellite and terrestrial communications. System control will be even more complicated when the control for satellite and terrestrial communications is merged under an integrated satellite/terrestrial communications concept. DCA and the DoD are directing considerable effort to resolving the issues of integrated control, and viable solutions are expected to be implemented before the end of the decade.

Evidence of the DCA and DoD concern for the problems of control is provided by the fact that three of the features of the Worldwide Digital System Architecture (WWDSA) (Reference 1) address control in its broadest sense:

- o WWDSA Feature B -- Ability to control many sources of connectivity intelligently
- o WWDSA Feature E -- Improved intra-network system control including the use of common channel signaling
- o WWDSA Feature M -- Improved inter-network system control, including better coordination between networks (e.g., satellite and terrestrial transmission networks)

WWDSA Feature B requires that the control of satellite communications be integrated with the control of terrestrial communications, and that tactical switching nodes be able to select any of a variety of transmission media as needed. Media could be selected on the basis of least cost, most suitable performance, call destination, and link availability. High priority users would be given precedence in the selection of the most suitable transmission media.

WWDSA Feature E enhances Feature B by requiring a high degree of realtime system flexibility through software controlled digital operation, continuing automatic assessment of system and link

performance and status, automated electronic patching and testing, and non-associative common channel signaling among switching nodes.

WWDSA Feature M goes still a step further by requiring shared data, automated displays, and cooperative control between different systems (e.g. tactical telecommunications, civil communications, and the Defense Communications System (DCS). Emphasis is on the cooperative reconstitution of badly fragmented communications from the bottom up by joining useable portions of still-operating communications systems or networks.

Since WWDSA sets forth guidelines for all DoD telecommunications systems, and the WWDSA features have been approved for planning by the JCS, it can be expected that the above features will gradually be incorporated into upgrades of present DoD communications systems and into new DoD systems as they are deployed. It is hoped that non-DoD telecommunications systems will also incorporate WWDSA features in order to provide greater survivability and greater interoperability of all military and civil communications within the NATO and other Allied communities.

ECONOMIC CONSIDERATIONS

The economic considerations relating to the integrated support of tactical operations by satellite communications are addressed for a hypothetical system which has an earth segment, a space segment, and a control segment. Costs are estimated over a 10-year life cycle, with all estimates in current dollars. The system is assumed to have an initial operational capability in the mid 1990's.

Research And Development

The research and development cost for the described capability is estimated to be $500 million.

Earth Segment

The earth segment is assumed to consist of 100 small satellite earth terminals. It is estimated that a single terminal, operating at EHF and equipped with anti-jam features, will cost on the order of $1 million in 1995. The O&M cost for the terminal is estimated to be about $200 thousand a year, or $2 million over a 10-year period. This results in a total 10-year cost of $3 million per terminal, or $300 million for a hundred terminals.

Space Segment

The procurement cost of the transponder, in orbit and onboard a multiple-transponder satellite, is estimated to be $50 million. The O&M cost is estimated to be $5 million per year, resulting in a total space segment 10-year cost of $100 million.

Control Segment

Ten separate control facilities are assumed, colocated with 10 of the small satellite earth terminals. Multiple control facilities are assumed to provide adequate diversification for system survivability. The procurement cost of each of the 10 DAMA control facilities is estimated to be about $1 million, with an annual O&M cost of $100 thousand. The total cost over a 10-year period is therefore $20 million for 10 facilities.

Total Cost

Based on the above estimates, the total cost for research and development, procurement, and ten years of operation and maintenance of the integrated satellite communications capability as prescribed by WWDSA would be $920 million. This is only a small fraction of the total cost of transmission media, and it would buy a considerable improvement in the overall communications survivability.

CONCLUSIONS

Satellite communications are already providing essential support to tactical operations. But that support is primarily for point-to-point communications over a range of 300 km or more. Next generation communications satellites need to provide increased capacity, an enhanced demand assignment multiple access, and be able to operate efficiently with small satellite earth terminals. It is estimated that the cost to perform research and development, procurement, and ten years of operation and maintenance for a satellite communications system containing a hundred small satellite earth terminals would be about $900 million in today's dollars. This would require only a small percentage increase in the cost of providing transmission for military communications. The large number of small satellite earth terminals, with an effective integrated satellite/terrestrial transmission control system, would allow satellite communications to be truly integrated with other communications media to provide increased survivability and more effective support of tactical, strategic and defense-wide operations.

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The discussion which followed this presentation appears in classified publication CP344 (Supplement)

EHF MILSATCOM SYSTEMS FOR TACTICAL USERS*

by

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ABSTRACT

Present tactical operations involve considerable long-haul communications (> 10 Km) which need to be both reliable and resistant to interference. Furthermore, the multi-service nature of many operations requires interoperability features in the communications system design. User-platform and prime power limitations as well as terminal production, installation, and maintenance costs for large user populations necessitate system configurations which accommodate small, low-power terminals.

Certain types of satellite communications (SATCOM) systems can provide these features. One approach involves the use of the wide bandwidth allocations in the EHF band (i.e. 30-to-50 GHz) to provide systems with larger capacities and to permit the use of robust spread spectrum modulation techniques. Evolution into these higher frequencies also offers the opportunity to incorporate signaling structures which are functionally common across multiple user communities. Such techniques provide interoperability possibilities while allowing more efficient use of spacecraft assets and minimizing the number of unique terminal developments. Furthermore, the concept departs from traditional SATCOM designs by incorporating increased satellite sophistication for reduced terminal size and complexity requirements. The associated spacecraft would employ advanced technologies such as uplink antenna discrimination, on-board signal processing, and downlink beamhopping.

This paper presents several system configurations for providing EHF service to tactical users, discusses the advantage of the advanced technologies incorporated, and indicates some spacecraft implementation possibilities.

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The discussion which followed this presentation appears in classified publication CP344 (Supplement)

SYRACUSE A SATELLITE COMMUNICATION SYSTEM USING SPREAD SPECTRUM MULTIPLE ACCESS

by

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ABSTRACT

SYRACUSE is a military communication system utilizing two 7-8 GHz repeaters (space segment) of the French communication satellite TELECOM 1 developed by the French Ministry of Communications and which will be launched by ARIANE. After describing the main characteristics of the space segment and the ground segment the paper will deal mainly with the SSMA system, general description, modem functional diagram, time management operation, synchronisation and resynchronisation of the network, modem interface base band and intermediate frequency.

Future trends of the SSMA system will be presented.

TACTICAL MILITARY COMMUNICATIONS BY SATELLITE RELAY AT HIGH LATITUDES

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ABSTRACT

Canada spans about 90 degrees of longitude and has requirements for tactical command and control communications as far north as at least to 84° north latitude. These facts create unique problems when considering requirements for communication by satellite relay.

The trend in military satellite communication for tactical purposes is towards the EHF spectrum. For currently practical power aperture levels geostationary EHF satellite communications are not considered likely to be militarily reliable for a country such as Canada. This is due to high path losses at latitudes common to Canadian operations. This paper examines the use of inclined orbits to solve this problem. Elliptic synchronous and semi-synchronous and low circular orbits are examined in terms of operating and tracking requirements, including ranges and Doppler effects at the user terminal. It is concluded that a highly elliptic inclined semi-synchronous orbit possesses significant advantages for EHF tactical communications at latitudes common to military operations in Canada.

Canada's geography, together with the emerging Alliance interest in the Extremely High Frequency (EHF) spectrum for future communications satellite planning, pose special military communications problems for Canada. Conventional communications satellites, both civil and military, are deployed in geostationary orbit. The view of Canada as seen from a geostationary satellite located south of the centre of Canada is shown at Figure 1. The fact that Canada, at the Arctic Circle (67.5° north latitude), spans 80° of longitude, and that our communications must reach to 84 or more degrees north latitude, causes problems which are only partly apparent from the perspective shown here.

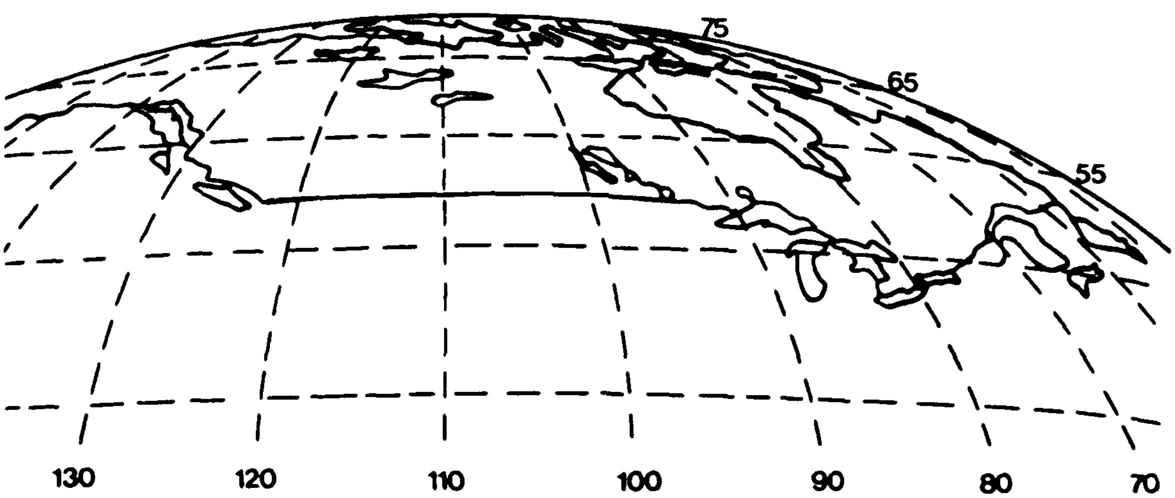


FIGURE 1

CANADA AS SEEN FROM GEOSTATIONARY ORBIT

DND has tested operationally a geostationary C-Band satellite link to a terminal located at 80° north latitude. The antenna elevation angle from this location to the geostationary satellite is only one degree. This link to 80° N latitude is only feasible because the Arctic receiver site employed two large, widely separated, antennas to achieve signal path diversity. This technique is feasible for large fixed installations but would not be possible for ships or aircraft, even if they were large. Moreover, there is a wide spread in the range of elevation angles to Canadian sites, due both to the large spread in longitude, as well as to the latitude effects. Antenna elevation angles to a satellite at 70° W vary from about 38 degrees at Ottawa to 11 degrees on the arctic coast at 67° N latitude. For service from a single satellite, these angles are below 25° on the north east coast and are down to 8° on the north west coast at latitudes of about 54 or 55 degrees.

Our coastal and east central regions are areas of significant rain attenuation effects. Furthermore, at the low elevation angles in the Arctic tropospheric scintillation problems are of concern. Hence when operation at EHF is established as a requirement, and all the tropospheric turbulence, oxygen, water vapour and rain attenuation margins are included, it is apparent that the areas of satisfactory military coverage from a single geostationary orbit position into Canada are significantly reduced, specifically if reliability of service is to approach 100% or so. Operations from more than one geostationary satellite position could improve the assured coastal coverage but could not improve service to the high Arctic. It is not immediately obvious that geostationary orbit operation is the logical choice for Canadian military tactical operations.

Accordingly, alternate orbits were evaluated as shown on Figure 2. Low polar and rosette orbit configurations had been looked at in a previous study. With orbital altitude approximately 15,000 to 16,000 nm, five to ten satellites were required in the rosette pattern, depending on the minimum design elevation angle (10° to 30°). Of course the number of required satellites would increase if the altitude is decreased, or if a polar orbit were selected instead of the rosette pattern. For reasons of cost and system problems associated with doppler and communication system control architecture these orbits were not considered further. Rather, a variety of inclined orbits were examined with periods from a half day to about four days. In this paper the following three orbits will be discussed:

a. inclined circular geosynchronous;

b. critically inclined elliptical geosynchronous (herein referred to as a "Tundra" orbit); and

c. critically inclined elliptic 12 hour (Molniya) orbit.

The ground traces of these orbits are shown on Figure 3. The saliant characteristics of these orbits are detailed at Table 1:

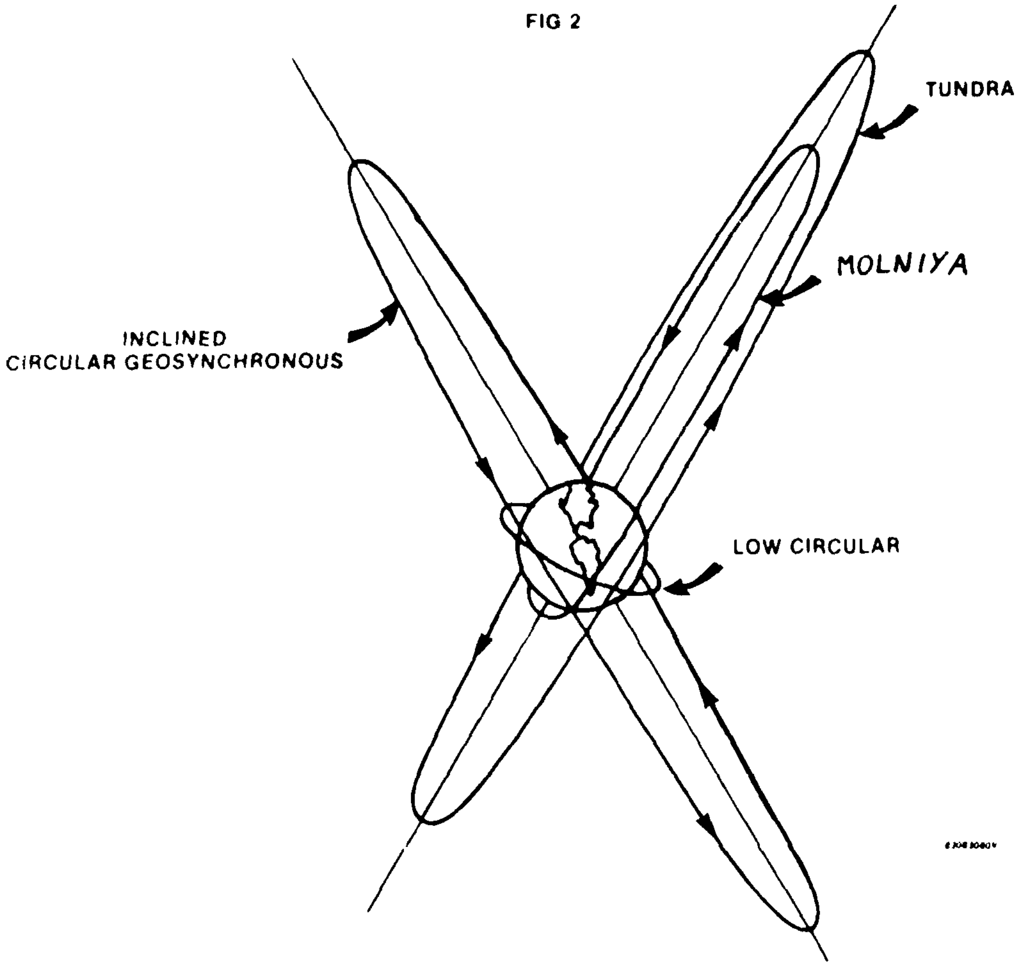
TABLE 1

Orbit	Apogee n.m.	Perigee n.m.	Incl. (deg)	Canadian Coverage Centre (Longitude)	Service Hours (Note 1)
Circular inclined geosynchronous	19323	19323	64°	100° W	± 4 from 64° N lat
Elliptic inclined geosynchronous (Tundra)	25025	13650	63.4	100° W	± 6 from apogee
Elliptic inclined 12 hr (MOLNIYA)	21700	320	63.4	100° W and others	± 3 and ± 4 from apogee

Note 1 - This is portion of orbital period that each satellite in the constellation is assumed in use for Canada/Arctic coverage.

An early question was whether the free space path loss would be a significant factor in the choice of orbit. The slant ranges involved with these three orbits vary from 15000 nm to 25000 nm. This is a spread in free space loss due to slant range from 91.1 db to 93.3 db. That is, the free space loss into any station in Canada, from geosynchronous (equatorial, inclined or elliptic), or from semi synchronous, are all in the range of 92.2 ± 1.1 db. This factor is therefore not significant in choosing between the orbits under consideration.

FIG 2



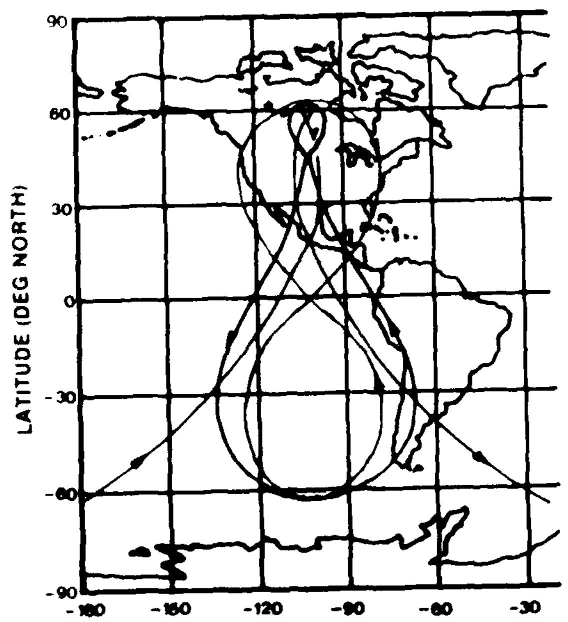


FIG 3
INCLINED ORBIT SATELLITE
GROUND TRACES

[illegible] terminal antenna elevation angles were examined, with the inclined circular geosynchronous orbit being evaluated first. The coverage boundary for maintaining a user terminal antenna elevation angle of at least 25° is shown in Figure 4. It has been assumed the satellite is operated from [illegible] hours before reaching its 64° most northerly latitude to [illegible] hours after reaching that point, thus requiring three satellites in the system to maintain continuous coverage. Coverage is symmetrical in both the north and south polar regions, a feature of little importance to Canada. However, the three-satellite constellation does provide the equivalent, in addition to the Arctic coverage, of [illegible] stationary coverage centered at the same west longitude equatorial crossing point. A two satellite system could be operated but continuous coverage would then be limited to either east or north of approximately 55° north latitude.

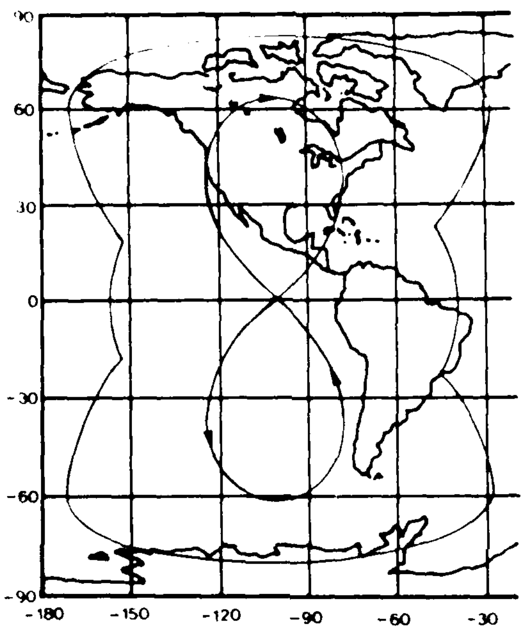


FIG 4
INCLINED CIRCULAR GEOSYNCHRONOUS
25° ELEVATION ANGLE COVERAGE

A two-satellite inclined elliptic geosynchronous constellation provides continuous coverage over the entire Canadian land mass and its environs. The user antenna elevation angles [illegible] are from reference 2 and are shown in Figure 5 for the two-satellite constellation. Antenna elevation angles are 25 degrees or more over almost the entire Arctic area of interest, and never less than 40° for the rest of Canada. The coverage obtained with a three-satellite deployment, i.e. with an in-orbit spare deployed and in use, is shown in Figure 6.

Typical inclined elliptic 12 hour (Molniya) orbit coverage is shown in Figure 7. The case shown is the eight-hour coverage per satellite where the apogee is located at [illegible] west longitude. A constellation with two satellites and one with four satellites were also evaluated, as were cases with apogees located at 155°, 95° and 75° west longitude. In all cases, except for the 155° apogee, the user terminal antenna elevation angles were 45° or higher. A Molniya with apogee at 75° West longitude, of course, has a second, or "offside", apogee at approximately 105° East longitude. A unique feature of the Molniya orbit is that the satellite at the offside apogee can also provide substantial service to Canadian sites. This factor is evident from Table 2.

COVERAGE OF TWO SATELLITE TUNDRA CONSTELLATION

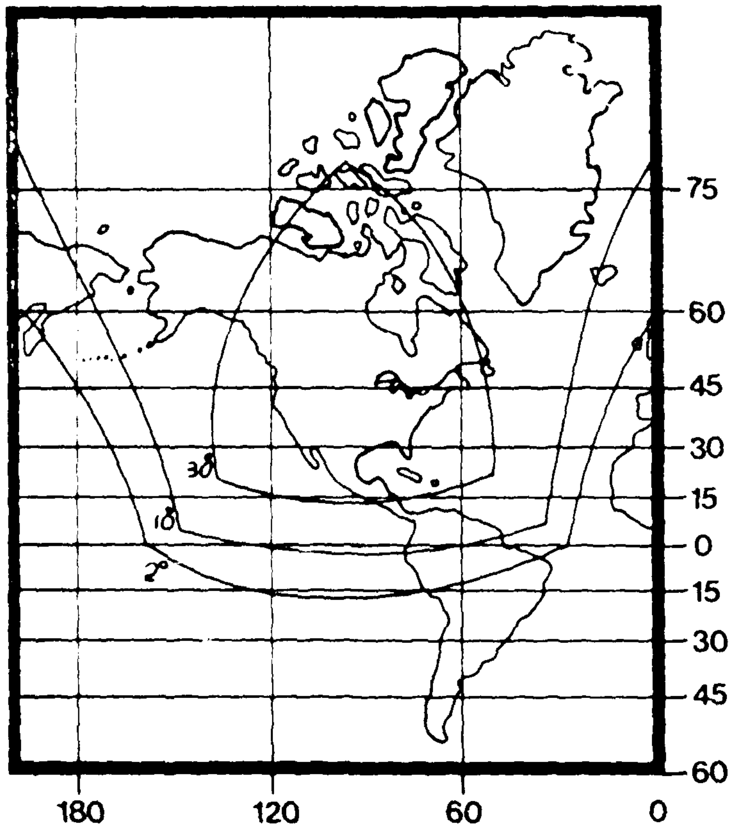


FIG. 5

TABLE [illegible]

[illegible]	[illegible] West Apogee		[illegible] #2	#2
	Antenna Elevation Angle			
	Min	Max		
[illegible]	[illegible]	58.[illegible]	4.[illegible]	[illegible]
[illegible]	[illegible]	6[illegible]	[illegible]	[illegible]
[illegible]	65	[illegible]4	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	5.[illegible]	21[illegible]
[illegible]	60	81	[illegible]	[illegible]
[illegible]	44	66	[illegible]	[illegible]
Massett	58	66	6.6	[illegible].4 [illegible]
[illegible]	[illegible]	[illegible]	10.[illegible]	8.[illegible]
	East Apogee		West Apogee	
[illegible] Norway	[illegible].6 [illegible].8		9.3 [illegible].9	

COVERAGE OF THREE SATELLITE TUNDRA CONSTELLATION

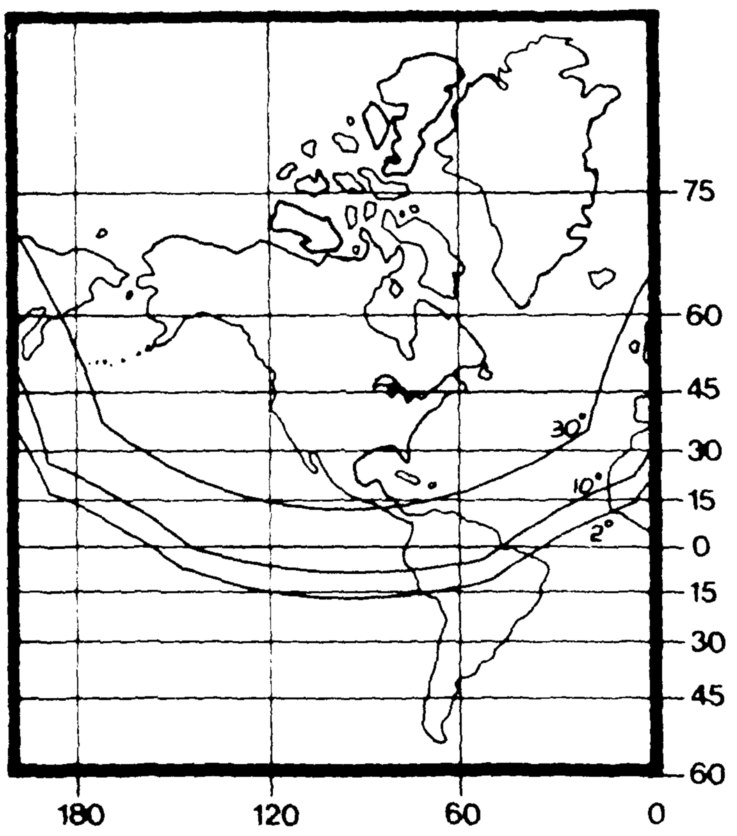


FIG.6

3 SATELLITE, MOLNIYA ORBIT COVERAGE

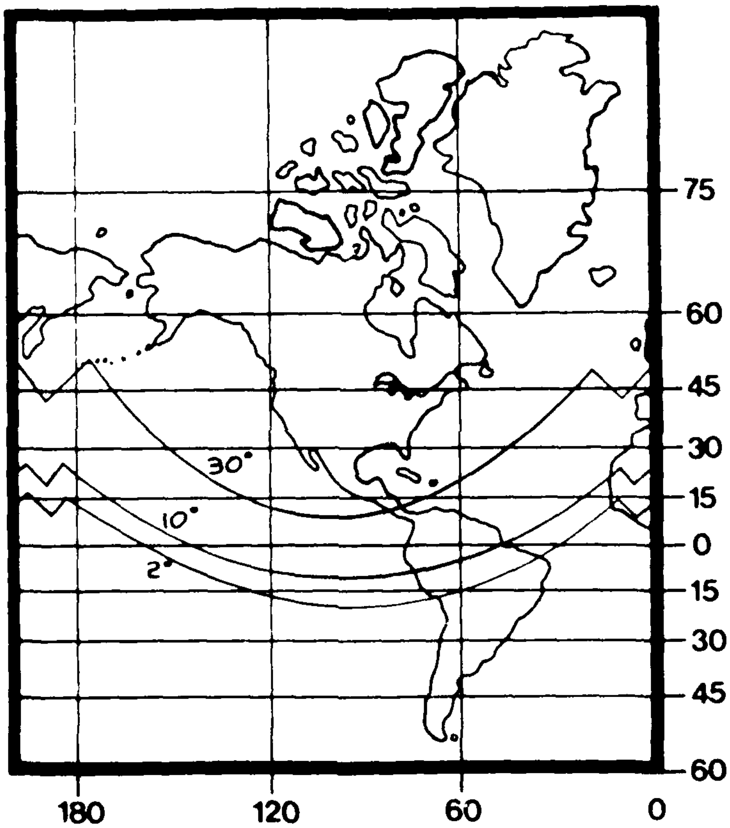


FIG 7

[illegible] are plotted for the inclin- [illegible] On this figure, [illegible] is at the top of the diagram. [illegible]

[illegible] N, [illegible] W

[illegible] N, [illegible] W

[illegible] N, [illegible] W, and

[illegible] N, [illegible] W

[illegible] hours before or after apogee or [illegible] orbit (i.e.; 0 = apogee; [illegible] before apogee). The radial scale is 90° [illegible]

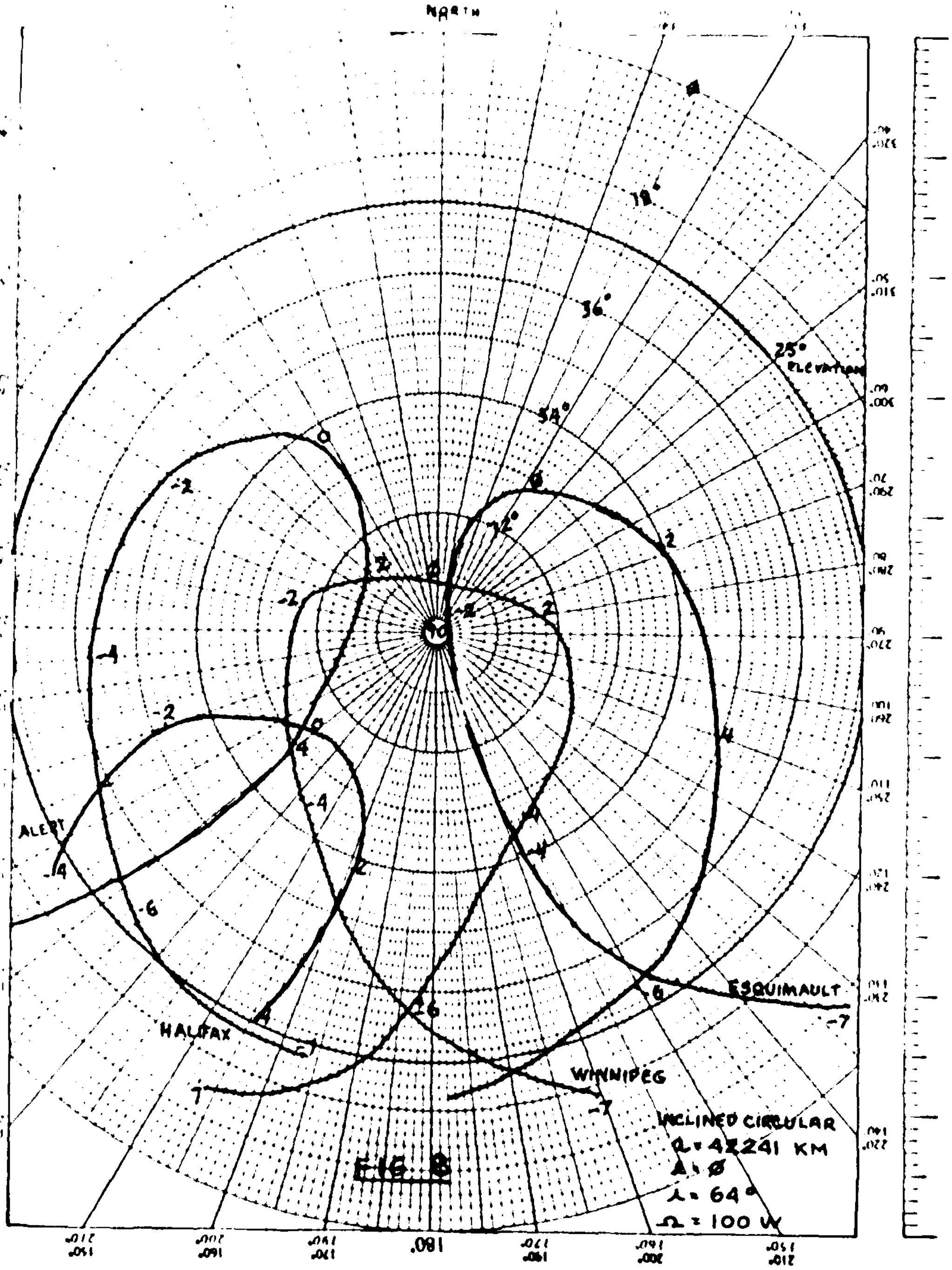


FIG. 8

Figure 9 is the similar plot for the Tundra orbit. The orbital parameters are again shown. The antenna tracking excursion is much tighter, particularly for the three-satellite case (plus and minus four hours operation from apogee). Parenthetically, if the orbit is altered to an eccentricity of about [illegible] each satellite can provide about [illegible] service to Canada, and the tracking excursion becomes almost a straight line.

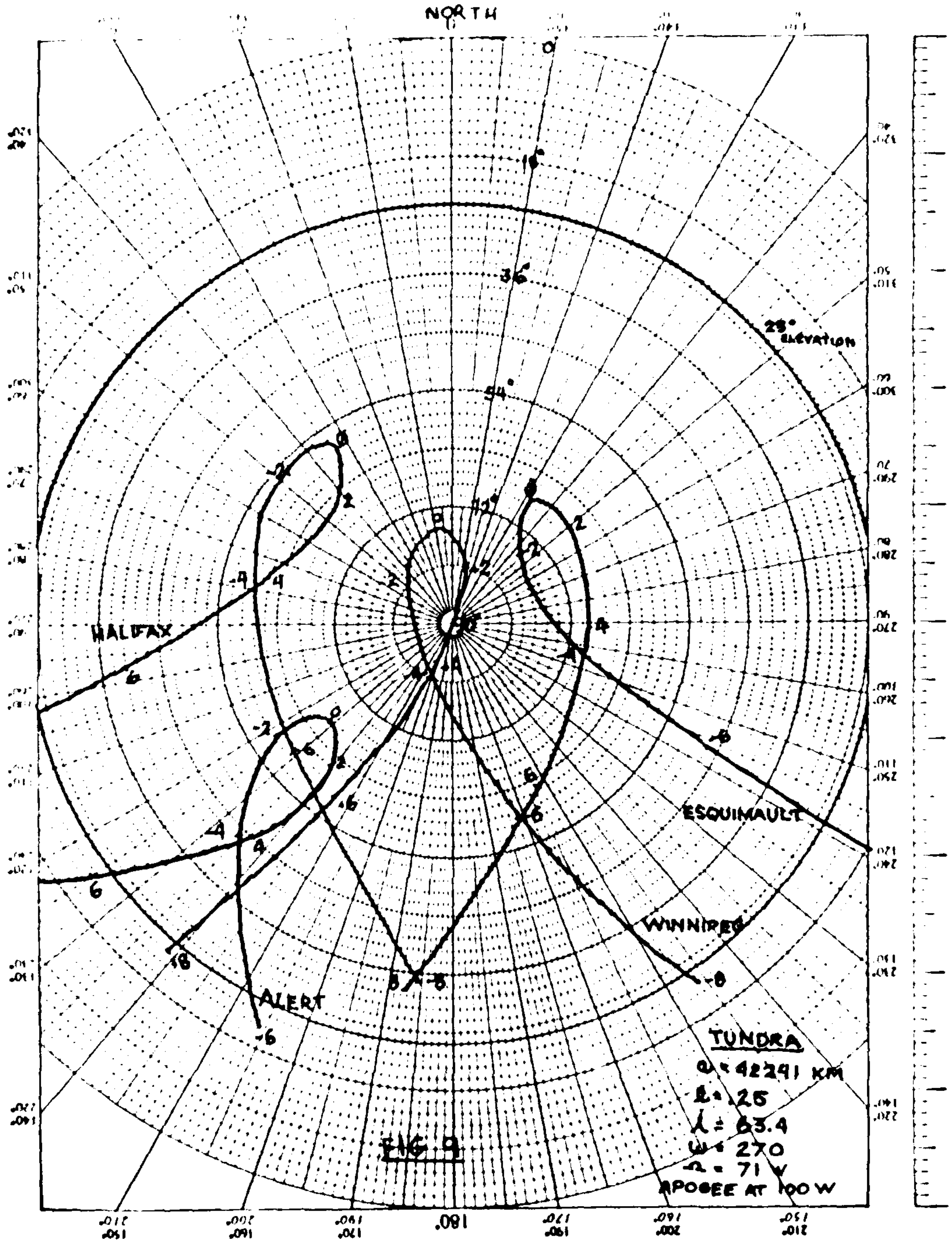


FIG 9

Figure 10 shows the antenna tracking excursion for a typical Molniya. The antenna tracking excursion is again tighter, almost linear. The antenna elevation angles to the west apogee are all above 45°, even for eight hours of service from each satellite. From the east apogee at 80°E, northern stations such as Alert can get 8 hours or so of service with antenna angles above 25°. Service is also possible to our coasts and to central Canada from the offside apogee, but only for those stations which can operate with antenna angles around 10 to 18 degrees. For comparison, offside apogee service to Lahr in Germany is almost 9 hours above 25°, and somewhat similarly for a north European station such as Boda, Norway, where the elevation angle is 40° or greater for eight

[illegible]

[illegible] this consideration, it was concluded that for those applications where a track- [illegible] the user terminal is a requirement, the choice of particular inclined orbit [illegible]. The Molniya orbit does, however, present a relatively [illegible] and may be the most attractive orbit for narrow beam [illegible].

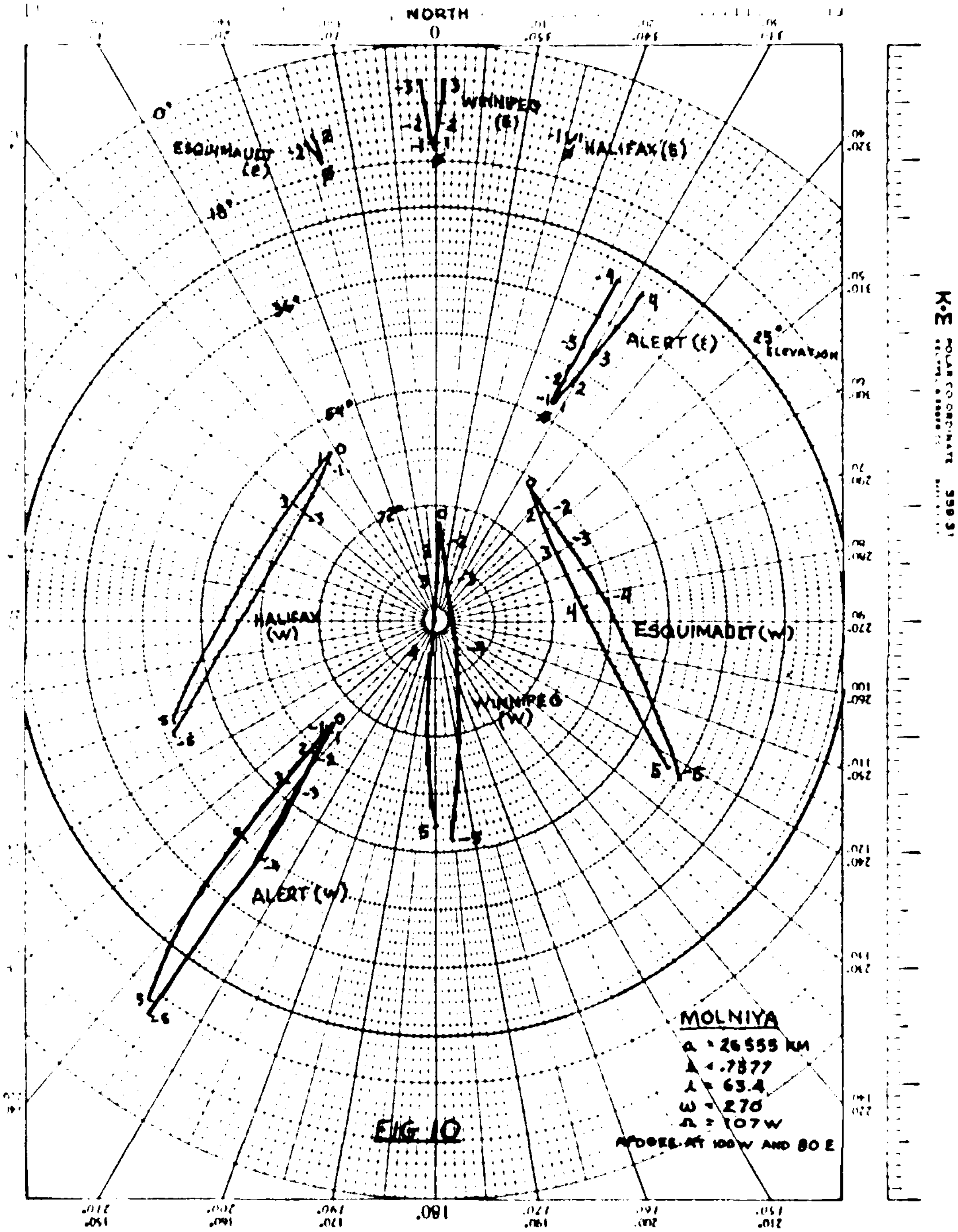
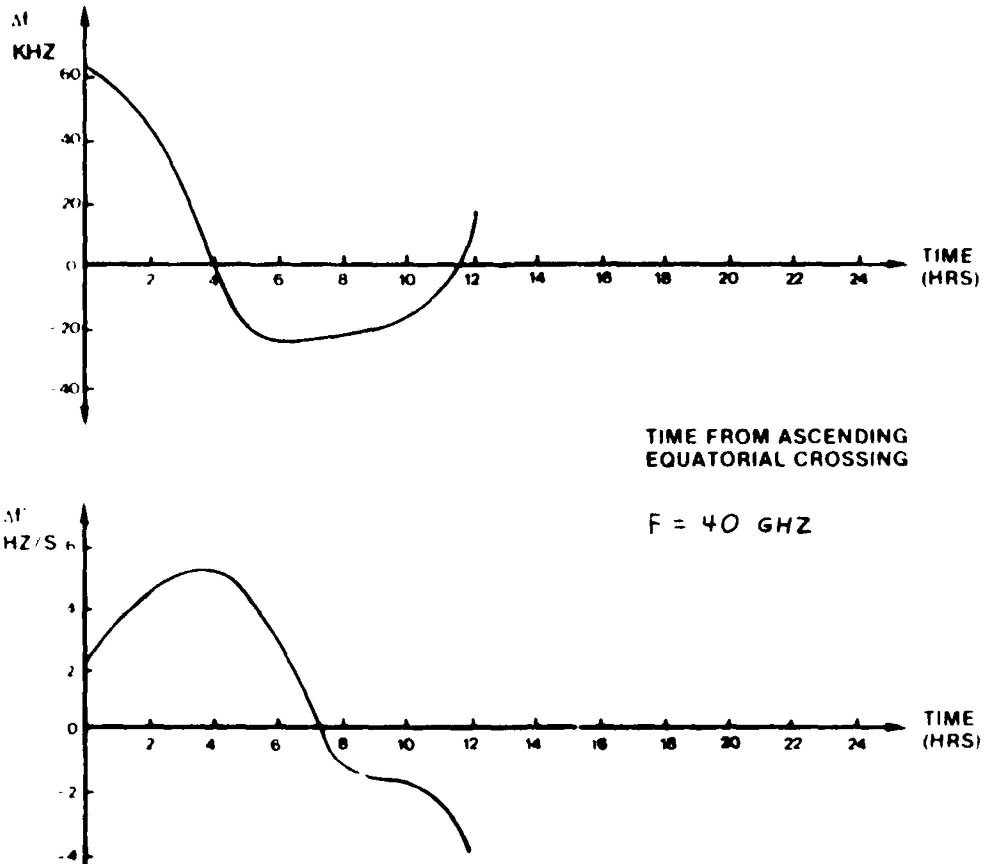


FIG 10

Another important design consideration is the doppler characteristic of the orbits under consideration. The doppler frequency and the doppler frequency rate of change are shown in Figure 11 for the inclined circular geosynchronous case. At 40 GHZ, for an eight hour operating period, the absolute magnitude of the doppler reaches about 25 KHZ. The rate of change varies from about 5 to - 4 HZ/sec over the same period.



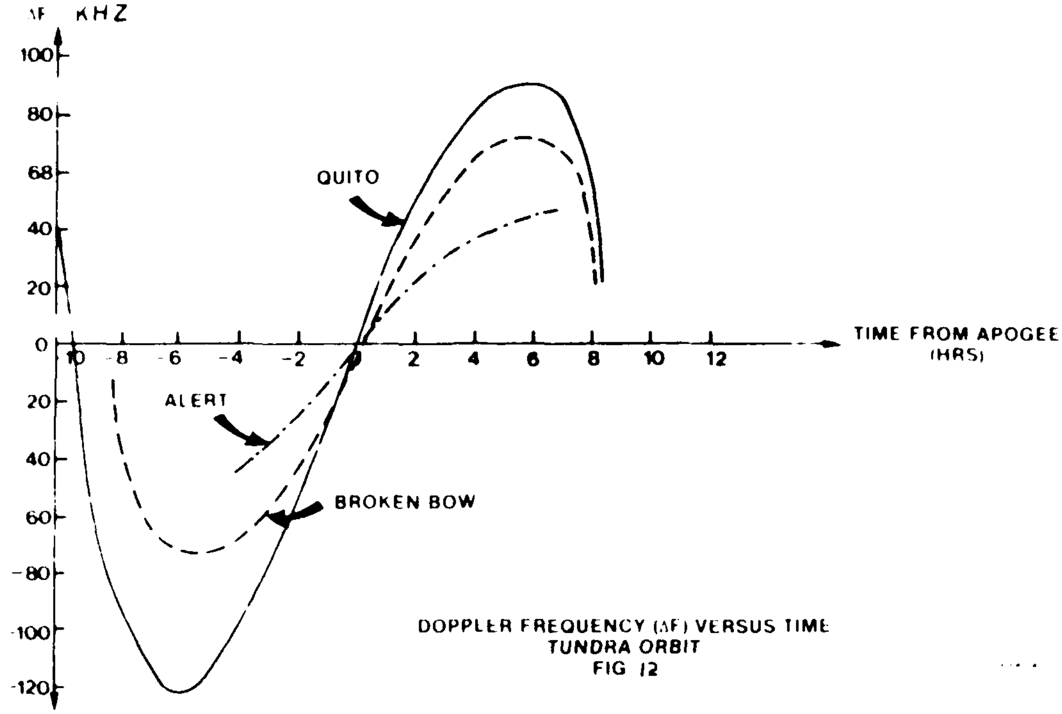
DOPPLER FREQUENCY (ΔF) AND RATE OF CHANGE (ΔF') VERSUS
TIME INCLINED GEOSYNCHRONOUS CIRCULAR ORBIT
FIG 11

As can be seen from Figure 12 and 13, the Tundra orbit doppler has a total [illegible] KHZ either side of zero, with the doppler rate having a maximum of [illegible] second. The doppler shift is about double the previous case but the doppler rate is [illegible] the same.

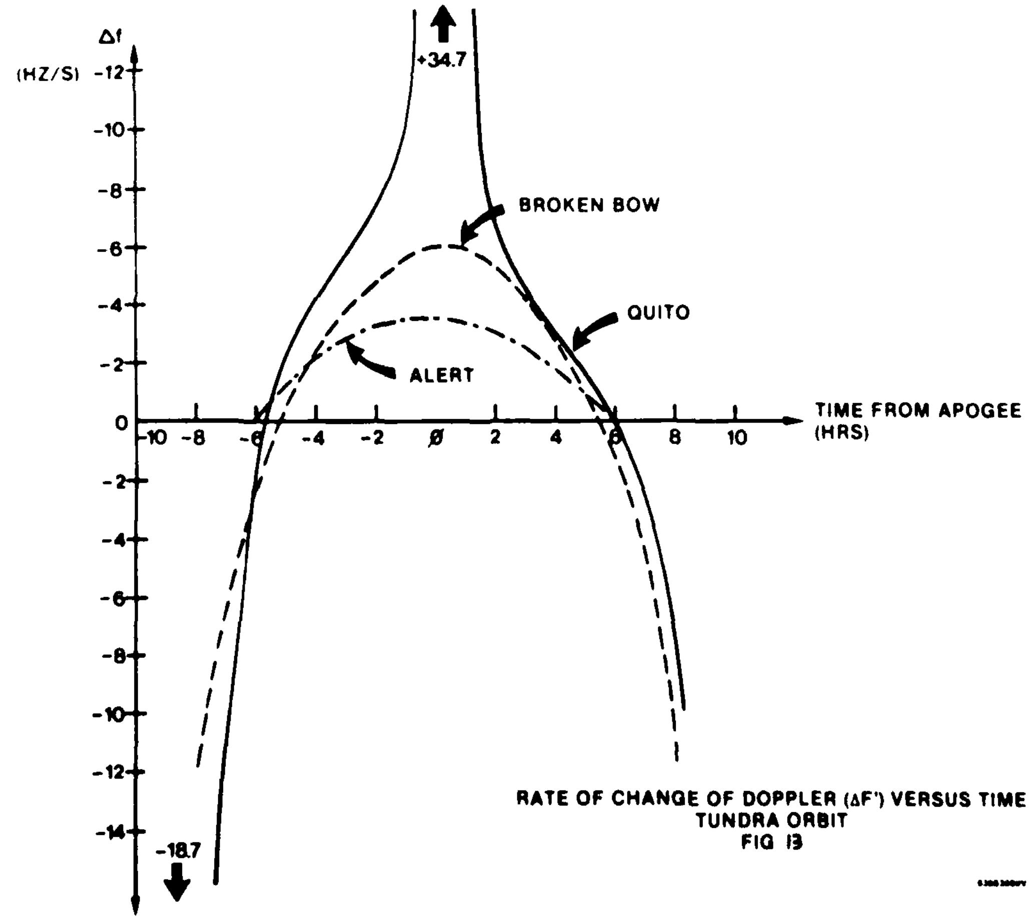
In the case of the MOLNIYA orbit the doppler shift, Figure 14, is higher in magnitude, [illegible] varies almost linearly with time. This can be seen from the rate of change [illegible] doppler curve, where this function, over the operating period is about 20 to 25 hertz per second.

The rate of change of doppler for the various orbits are plotted together on Figure 15. Also shown is a geosynchronous orbit with a perigee around 600 n.m. This is a configuration which gives about 21 hours of coverage per day per satellite for Canada. The doppler characteristics also do not appear to be an overriding factor in choice of orbit. The circular case has a lower doppler rate, but the other cases may be more easily represented by linear functions.

The Molniya orbit has a very important impact on launch requirements. For a vehicle being launched to a Molniya orbit there is a much reduced weight requiring to be boosted, compared to a vehicle being launched to geosynchronous orbit. The Hohman transfer orbit for the geosynchronous case is essentially almost the final orbit for the Molniya case. The Molniya vehicle does not require an apogee kick motor. The apogee kick motor, with its fuel, is typically 45 to 50% of vehicle weight in the transfer orbit. An orbit adjust capability is required, however, due to precessing of Molniya orbits with the influence of sun and moon. In addition the Molniya requires substantially less batteries than conventional designs. This is because the Molniya does not require payload operation during eclipse (the spacecraft, except for rare eclipsing by the moon, is never eclipsed within four and a half hours either side of apogee).



DOPPLER FREQUENCY (ΔF) VERSUS TIME
TUNDRA ORBIT
FIG 12



RATE OF CHANGE OF DOPPLER (ΔF') VERSUS TIME
TUNDRA ORBIT
FIG 13

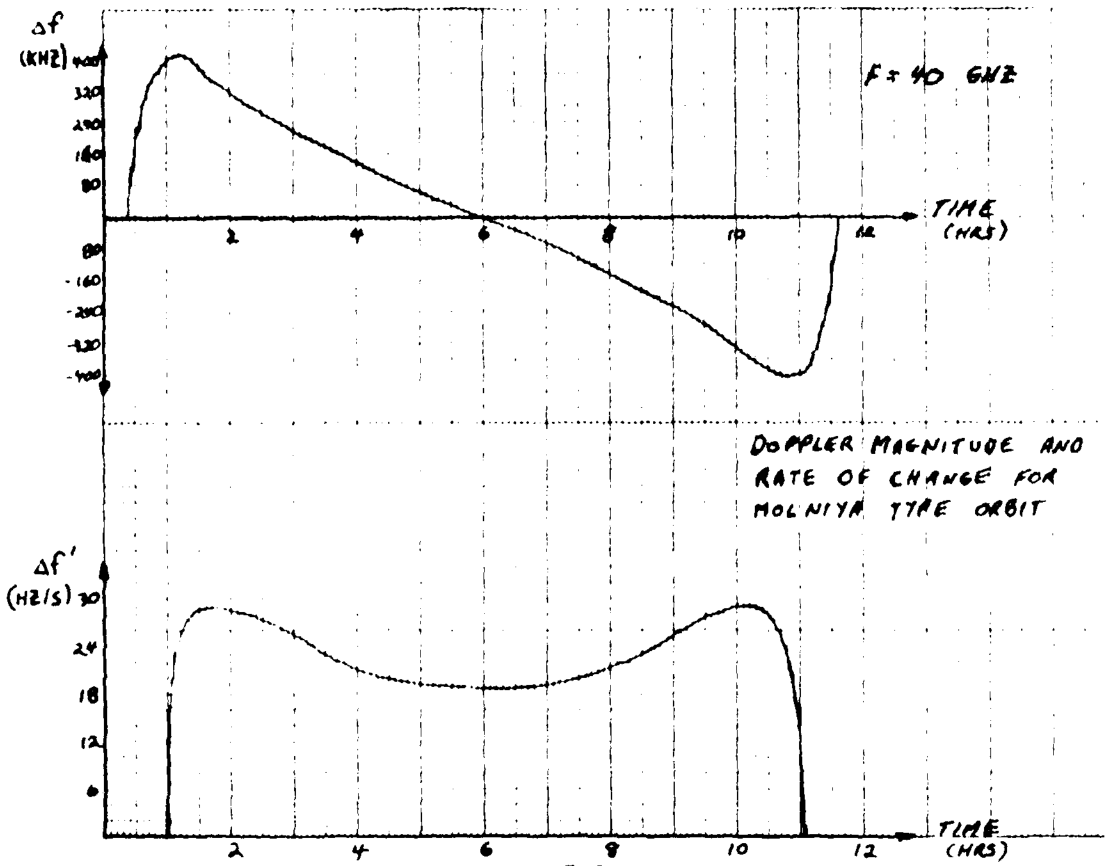
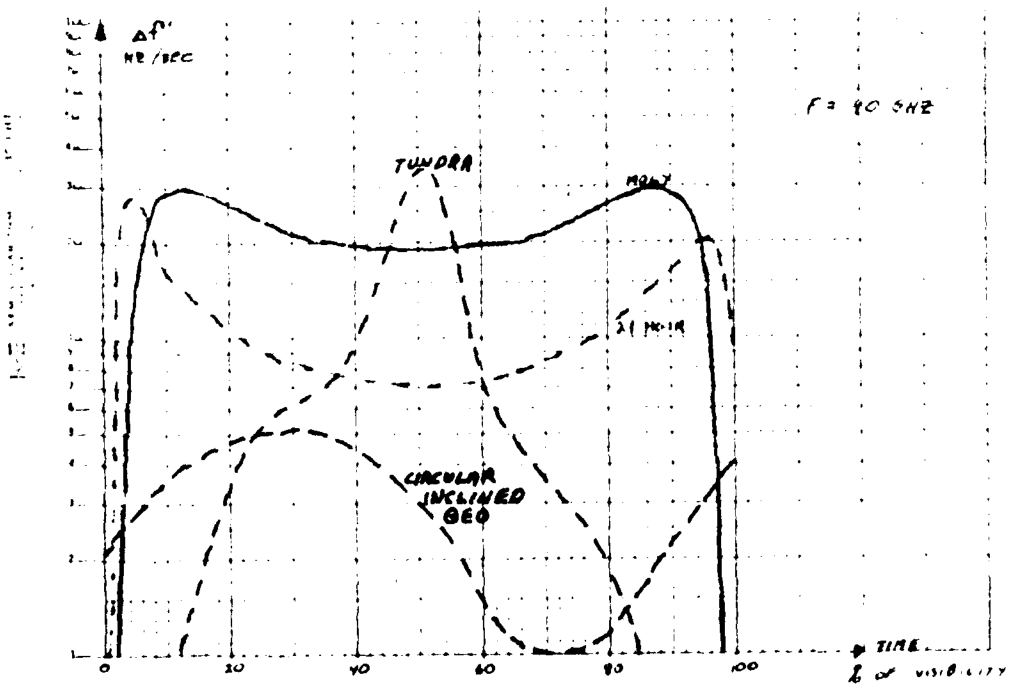


FIG 14

FIG 15
RATE OF CHANGE OF DOPPLER
FOR SELECTED ORBITS



Solar cell deterioration can be a significant design consideration. For geostationary vehicles the required allowances for this factor are well understood. The Tundra orbit perigee of almost 14,000 n.m. is above the main Van Allen effects and solar cell degradation will be similar to the effects at geostationary orbit. However, solar cell deterioration is a more serious factor in the semi synchronous case. Molniya vehicles transit the Van Allen regions twice on each orbit, i.e., four times each day. We have been given estimates of solar cell degradation for Molniya vehicles which vary widely. However, this solar cell degradation may be significantly less of a weight penalty than the battery weight saving due to elimination of eclipsed operations with Molniya orbits.

Vulnerability to anti-satellite weapons is a factor receiving increasing attention. Quite apart from physical hardening or self defence measures, each of these three inclined orbits present targets expensive to attack. Attack would require commitment of a separate ASAT against each spacecraft in the constellation. Furthermore, a very powerful booster is required for the ASAT vehicles to attack satellites not in low earth orbit. If the commitment of an ASAT were known, then in the case of the semi-synchrorous MOLNIYA configuration, an evasive manoeuvre might be practical and effective. This is because a small energy input at or near apogee can effect substantial perigee changes without significantly affecting subsequent apogee operations. To a lesser degree, the same comment can be made for the inclined elliptic TUNDRA orbit.

When thinking of vulnerability, there is sometimes a tendancy to look at cases class by class. You can say that all those spacecraft which regularly transit the Van Allen belts belong to a class which would be particularly vulnerable to trapped debris if a nucelar weapon were ever detonated at high altitude. Satellites in geostationary orbit are another vulnerability class. A satellite launched retrograde to geosynchronous altitude would encounter every satellite on geostationary orbit in a period of 12 hours. Generally speaking, a satellite in a Molniya orbit costs 20% less than a satellite in geosynchronous orbit. This can be a very powerful argument, vulnerability or survivability arguments not withstanding.

The effect of a spacecraft failure is another consideration. The inclined circular geosynchronous orbit requires three spacecraft for continuous Canadian coverage. Loss of any one spacecraft results in very substantial periods of outage. This vulnerability can be reduced through use of a four-satellite constellation. In the case of the elliptic Tundra orbit, each spacecraft can provide service to stations in Canada for, typically, 14 hours or more per day leading to a two satellite requirement. Again vulnerability to loss of service can be reduced by including an extra, third, satellite. In the case of a three-satellite TUNDRA deployment loss of one satellite will initially result in a time period without service for two hours once each day until the two remaining satellites are moved to eliminate this outage. Conversely, for the same boost energy, the original orbit could have been designed to provide over 20 hours service per satellite.

In the case of a three-satellite Molniya constellation, loss of one satellite will cause one eight-hour period where service must be obtained from a satellite on the offside apogee, providing it is in view. In effect, this results in no interruption of service in the region approximately from the Arctic circle (67°N. latitude) to the pole. However, south of the Arctic circle there will be degradation of service which will depend on the geographic location and the minimum antenna elevation angle required for the user terminal equipment at that location. A four-satellite constellation could adjust to compensate for one failed satellite. For those stations requiring only 10° antenna elevation angle, two Molniya satellites phased six hours apart can provide uninterrupted service as far south as about 55° latitude.

Conclusions to be drawn from this discussion would perhaps include:

a. all three orbits require the user terminal to have a tracking antenna if the advantages of narrow beam EHF operations are to be realized;

b. the circular orbit requires the largest antenna angular excursions of these three orbits, the Molniya the smallest, with the Tundra somewhere in between;

c. there are some narrow beam antenna design opportunities with the Molniya which may not be available on the other two orbits;

d. the doppler magnitude is higher on the Molniya but the doppler rate is not significantly different between the three orbits;

e. how gracefully the various constellations fail is very important. In some respects the Molniya does rather well; and

f. at launch costs of about $22,000 per pound to geosynchronous orbit, the Molniya weight advantage can be very significant.

What choice does one make? Canada has not yet initiated a military communications satellite deployment program so Canada has not yet had to make any firm choices. However, from evaluation so far of these three orbits the MOLNIYA certainly has many distinctive advantages for solution of the Canadian military communications problems. In addition to factors discussed above, the reduced energy requirements, i.e. reduced mass to be boosted, leave options open for future consideration. With this vehicle you are not locked in to large boosters. Who knows - someday it may be expedient, as well as cost-effective, for Canada to launch her own spacecraft. This would be much more easily

[illegible] possible with a Molniya vehicle than with the other orbits considered.

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2. "The Tundra Orbit, a [illegible] Plane Satellite Constellation Optimized for Continuous Coverage of the Whole of Canada", CRC Space Satellite Office, NDE, Ottawa, 16 Mar 81.

(U) Discussion which followed the presentation appears in classified publication CP 344 (Supplement)

UK SKYNET 4 COMMUNICATIONS SATELLITES

by

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ABSTRACT

This paper describes the principal features of the UK Skynet 4 Satellites, which will provide enhanced tactical and strategic communications facilities for the British forces. The satellites are being built by British Aerospace and Marconi Space & Defence Systems under contract from the UK MoD, with the first launch planned for 1985.

The satellite is based upon the proven ECS vehicle and employs 3-axis stabilisation in geostationary orbit. The total power consumption of about 1.2 kw is derived from solar panels and the on-station mass is about 660 kg. At a position of 1°W, the first satellite will be visible from Europe, the East coast of America and the Middle East.

SHF remains the workhorse of satellite communications, and the SKYNET 4 satellite contains four wideband transparent transponders designed to handle a large number and variety of users. A number of reconfigurable antenna options may be selected, including Earth, NATO, European, and Central European cover. Another notable feature is the adaptive nulling antenna; this may be controlled by telecommand to mitigate the effect of uplink jamming.

Further protection is supplied by the Processing Channel. This employs a spread-spectrum uplink which is despread on the satellite to give both secure broadcast and telecommand. This self-contained receiver represents a significant achievement in on-board processing.

Future trends in Satcoms are undoubtedly towards EHF, with relative benefits of uncluttered spectrum, and reduced jamming threat. Skynet 4 incorporates an experimental 44 GHz receiver, with a downlink at SHF. This will be used for R&D purposes and to assess the potential of EHF.

Together with narrowband UHF channels, SKYNET 4 will offer a significant and versatile communication service into the 1990s. This paper highlights some of the satellite features with their rationale, and points to some likely future directions.

MINIMISATION OF SYSTEM VULNERABILITY IN NAVAL SATELLITE COMMUNICATION NETWORKS

by

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ABSTRACT

The advent of the microprocessor has readily enabled the modern implementation of complex modulations and simplified the control of communication networks. This has encouraged a fresh examination of the architecture employed in the United Kingdom's Naval SHF satellite communications.

The principle of the present SATCOM organisation, including threat scenarios are discussed. Models are developed that are both compatible with current operational practice and future requirements.

The concept of system distribution is then applied, the path of a signal being traced from operational origin to destination. The vulnerability of each path node is discussed and countermeasures which include alternate modes that minimise weaknesses are described.

Such a treatment leads to an enhanced traffic capacity and realises a system which is readily expanded to meet changing increased requirements. It also impinges on build standard criteria and can lead to a more economic solution than currently practised.

THE FERRANTI TACTICAL SHF SATCOM STATION (MANSAT*)

by

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ABSTRACT

The Communications Group of the Royal Signals and Radar Establishment (RSRE) Malvern, England, pioneered development of small tactical SHF (7 - 8 GHz) satellite ground terminals. The concept of an SHF terminal small enough to be carried on a man's back has been further developed by Ferranti Electronics Limited, Poynton, Cheshire, England, under contract to RSRE. Field trials models weighing 17 Kg including antenna, power supply and carrying frame have been manufactured and extensively trialled in field conditions. As currently configured the equipment provides either 50 bit/sec telegraph or analogue speech (both duplex). A digital secure speech facility is currently being developed. Depending on the satellite antenna system in use the terminal can either be worked to a main satellite ground station or another small station. The equipment characteristics allow it to operate freely with the SKYNET, DSCS and NATO satellites.

The performance of the station and its principal components are outlined in this paper, together with current developments.

* a trade mark of Ferranti Electronics Limited.

TACTICAL SATELLITE TERMINALS FOR LAND AND AIRBORNE C³ APPLICATIONS

by

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ABSTRACT

The increasing RF power that has become available from the growth in size of satellites over the years has been used by the owners of satellite systems in a *number of different* ways. Civil authorities such as PTTs and Commercial Carriers have used the extra power for increased channels and for higher data rate services, third world nations have benefited from simpler and cheaper earth stations and the military have developed a whole range of small terminals for tactical use. These small terminals have extended the C^3 lines from the highest echelons of command to the individual elements of the fighting unit. A concept aptly summarised in the phrase "President-to-foxhole communications".

The paper will briefly describe the operational need for long distance, continuously available, error-free communication and the melding of Communications with Command and Control.

Ground satellite terminals in use and in development will be described and their technical characteristics discussed. Current work on a satellite terminal for the Nimrod long range maritime patrol aircraft will be described.

The EW threat is ever present and satellite systems will increasingly have to be designed to minimise the effects of jamming and interception. The paper will consider techniques employed such as spread-spectrum modulation and frequency hopping for terminals operating in the military SHF satellite band.

THE GLOBAL POSITIONING SYSTEM (GPS) PROGRAM STATUS UPDATE

[illegible]

[illegible] Wa[illegible] H [illegible]
[illegible] Development and Test [illegible]
[illegible] YEE
[illegible] W[illegible] Postal Center
[illegible] CA [illegible] USA

ABSTRACT

[illegible] SEP [illegible] a worldwide, day [illegible] [illegible] and 0.1 metre per second [illegible] applications and will enable users to operate [illegible] control segment, and user segment. The GPS [illegible] successful concept validation phase. [illegible] testing [illegible] DSARC III production decision is scheduled for May 1984. This [illegible] system capabilities, test results, schedule [illegible] operational considerations will also be addressed. User [illegible] The talk will be unclassified.

[illegible] GPS [illegible]

GPS SYSTEM FIELD TESTING

by

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The test program for GPS Phase II User Equipment (UE) is extensive; it includes, as noted in Figure 1, seven different kinds of tests ranging from in plant tests to initial operational test and evaluation. They differ by time, purpose, and test agency. In this presentation, we will be primarily concerned with field development, test, and evaluation (DT&E) tests.

INPLANT

- DESIGN VERIFICATION
- PARTS CERTIFICATION
- SOFTWARE AND HARDWARE QUALIFICATION
- MAINTAINABILITY DEMONSTRATION AND RELIABILITY GROWTH TESTS
- ACCEPTANCE

SYSTEM INTEGRATION LABORATORY

- UE INTERFACE COMPATIBILITY

MODIFICATION CENTER

- HOST VEHICLE - UE INTEROPERABILITY
- MODIFICATION INTEGRITY AND SAFETY OF FLIGHT
- ELECTROMAGNETIC COMPATIBILITY

FIELD DEVELOPMENT, TEST, AND EVALUATION (DT&E)

- RANGE READINESS
- INITIAL DEBUG
- PERFORMANCE

DT&E OPERATIONAL READINESS

- SPECIFICATION COMPLIANCE
- INTEGRATED PERFORMANCE

COMBINED ENVIRONMENTAL RELIABILITY TESTS

INITIAL OPERATIONAL TEST AND EVALUATION (IOT&E)

Figure 1. GPS Phase II User Equipment Tests

All of these tests involve the totality of the GPS system (Figure 2). They use signals from the current satellites to test the user equipment and thereby are testing the GPS satellites and their ground control.

- USER EQUIPMENT
- INTEGRATED WITH HOST VEHICLE
- CURRENT SATELLITE CONSTELLATION
  - 5 SATELLITES WITH ATOMIC CLOCKS
  - 1 SATELLITE WITH CRYSTAL CLOCK
- INTERIM CONTROL SEGMENT
  - 4 MONITOR STATIONS
  - MASTER CONTROL STATION
  - DAILY UPLOADS

Figure 2. Total System Testing

At present, the GPS satellite constellation consists of six satellites. One of them (Navstar 1) employs a backup crystal clock a very good crystal clock indeed, but its signals are of somewhat inferior quality. The other five (Navstars 3,4,5,6 and 8) provide very good quality navigation, and for the purposes of this presentation, we will limit our attention to those five satellites. The interim control segment, which will be replaced by the operational control segment beginning in 1985, has four monitor stations (Guam, Hawaii, Alaska, and Vandenberg Air Force Base) and a master control station and satellite upload station which are also at Vandenberg Air Force Base. The master control station uses satellite data received at the monitor stations, computes the clock errors and ephemeris for each satellite and predicts these ahead. Once a day its newly generated uploads are sent to each satellite.

As a specific example of what the satellite constellation means to a user or to a test team, let us suppose that we are conducting a GPS test here at Langley today, and look at the satellite coverage we have. Figure 3 shows the elevations angles we see to each of the five satellites which are operating with atomic clocks. We see that at 3:00 pm, local time, this afternoon which is 1900 GMT we are in the middle of a period of five satellite visibility, a period which is a little more than 3 hours long. At this time, two of the satellites are at about 30 degrees elevation, two near 45 degrees and one is above 55 degrees.

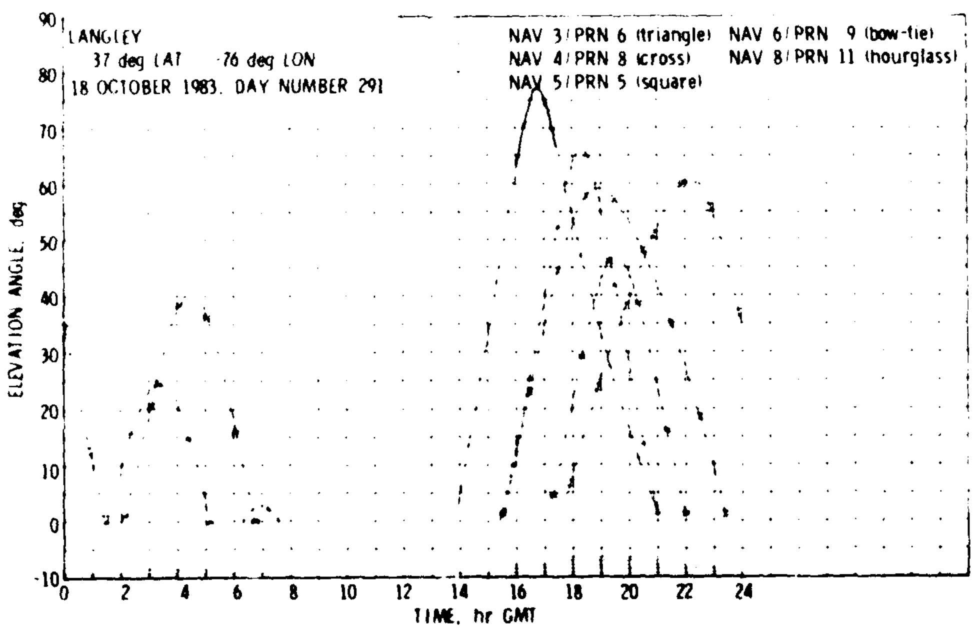

Figure 3. Elevation Angles to Visible Satellites - Langley

Figure 4, correspondingly, shows the azimuth angles to the satellites. On this figure, 0 degrees is north, 90 degrees is east, and south is both + 180 degrees and 180 degrees. With some effort we can determine that one satellite is toward the northeast, two to the northwest, one west, and one southwest.

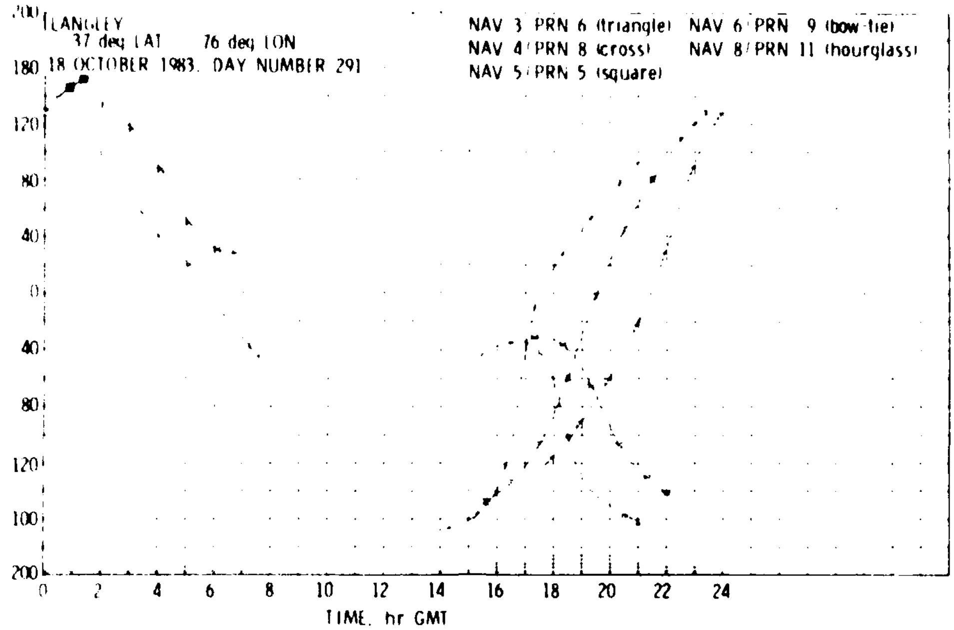

Figure 4. Azimuth Angles to Visible GPS Satellites

Before we take up the quantitative aspect of satellite geometry which is, discouragingly, called "dilution of precision," we should go back for a while to the control segment: in particular, to the question of <u>when</u> the newly calculated daily uploads are sent to the satellite. As noted in Figure 5, the basic consideration governing the time of uploads is to provide good quality uploads that is, ephemeris and clock predictions to support tests at Yuma. To that end, data are collected for as long as possible, and the doctrine at the master control segment is to have at least one set of data from each satellite taken at the Vandenberg monitor station which is the one closest to Yuma. Those Vandenberg data must be taken when the satellite is at least 10 degrees above the horizon, to minimize the adverse consequence of my errors in the model for tropospheric refraction.

- SUPPORT 4-SATELLITE TESTING AT YUMA
- ORDERLY WORK LOAD AT MASTER CONTROL STATION
- SATELLITE MEASUREMENTS AVAILABLE FROM VANDENBERG MONITOR STATION
  - ABOVE 10 DEGREE ELEVATION

Figure 5. Daily Satellite Upload Schedule

Figure 6 shows the satellite elevations as seen from the Vandenberg monitor station, and it also shows that Navstars 3 and 4 were scheduled for uploads at 1630 GMT, Navstar 8 for 1700 GMT and Navstars 5 and 6 for 1730 GMT. In fact, the whole upload schedule works backwards from Navstar 5:

> The Kalman filter in the MCS runs on a 15-minute cycle. Navstar 5 reaches 10 degrees elevation from Vandenberg at 1700, data from it are incorporated into the filter for the 1715 time point, and then a new upload message is prepared and sent to the satellite, which begins to transmit the new message at 1730.

From the point of view of the user or tester, what is important is that the final uploads for the constellations take place at 1730.

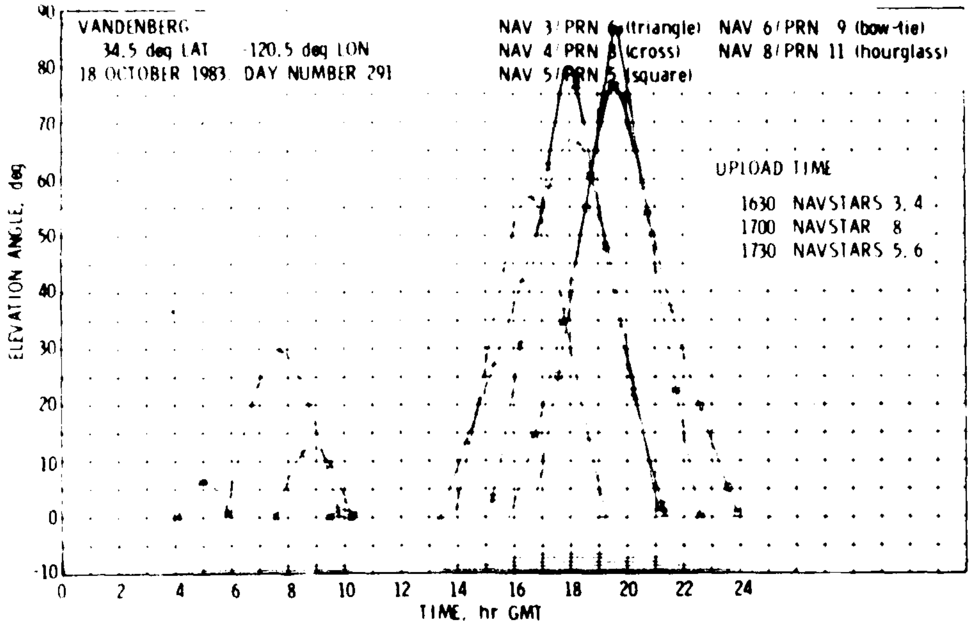

Figure 6. Elevation Angles to Visible Satellites

The PDOP (position dilution of precision) is a measure of how satellite geometry affects user navigation. Under the assumption that the user's pseudo ranging errors are normally distributed, with the same standard deviation for each satellite, and that the errors are uncorrelated from one satellite to another, the expected 3 dimensional navigation error will be the standard deviation multiplied by the PDOP. Thus, the lower the PDOP value the better.

We can get some feel about the magnitude of PDOP from the fact that the prime specification for the GPS system defines the satellite system as being "available" to a user if he has at least four satellites in view and these give a PDOP which is 6 or less.

Figure 7 shows the PDOP achieved here at Langley by the current constellation of GPS satellites. Four satellite visibility begins when Navstar 6 rises and the PDOP is about 6 1/2. Half an hour later, Navstar 5 rises, and five satellites are in view. From that time until 2100 4:00 o'clock this afternoon here- the PDOP given by the best combination of four satellites lies between 3 1/2 and 5. What we have here is 3 1/2 hours of four or five satellite coverage after all uploads have taken place, with excellent geometry. Thus, for length of coverage and favorable geometry, this would be an excellent place at which to test GPS!

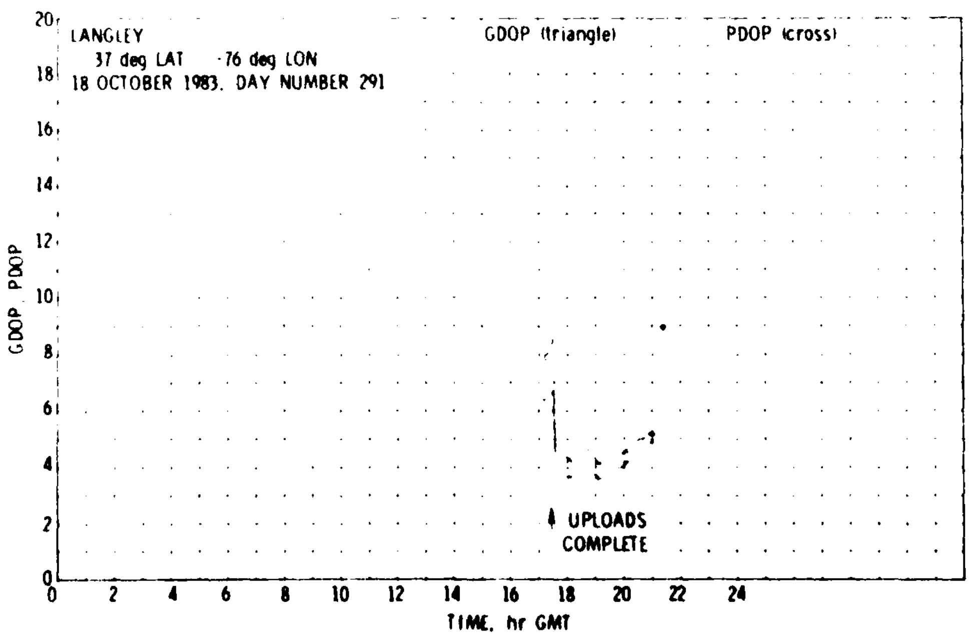

Figure 7. Four-Satellite GDOP, PDOP

I'm not aware of any formal GPS user equipment testing planned for the Norfolk area, but tests are planned for many places indeed. In fact, as shown in Figure 8, the sites used in the user equipment test program are stretched across the North American continent, and the carrier and the submarine will take user equipment in operational deployments into the Pacific during initial operational test and evaluation.

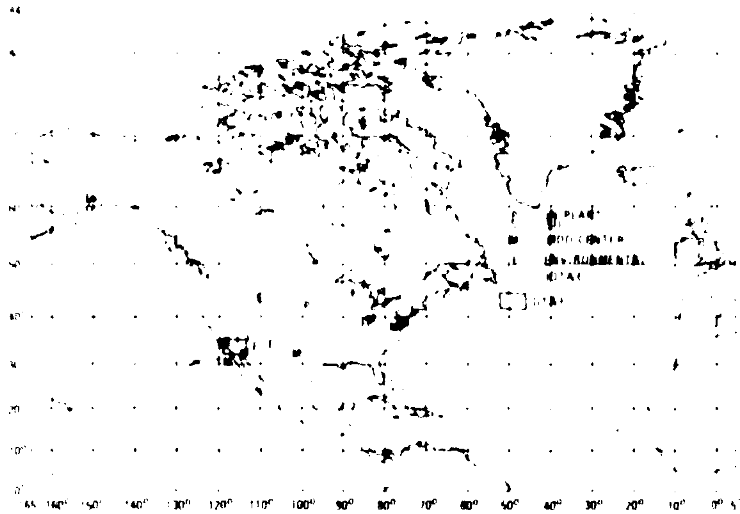

Figure 8. Test Locations GPS Phase II User Equipment

Let's look at the visibility times for four or five satellite coverage at the two extreme locations identified for environmental testing.

At Panama, as shown in Figure 9, there is an initial period before the last upload in which the PDOPs are large and increasing rapidly. The constellation is saved from a singularity by the rise of Navstar 6. Thereafter, there is a prime 1 hour and 45 minute period of good geometry involving satellites with current uploads, which is then followed by almost 3 hours with PDOPs in the 10-12 range. Because the PDOP is outside of the specification availability limit, that period should not be used in assessing navigation accuracy, but it could perfectly well be used for functional tests, human factor tests, etc.

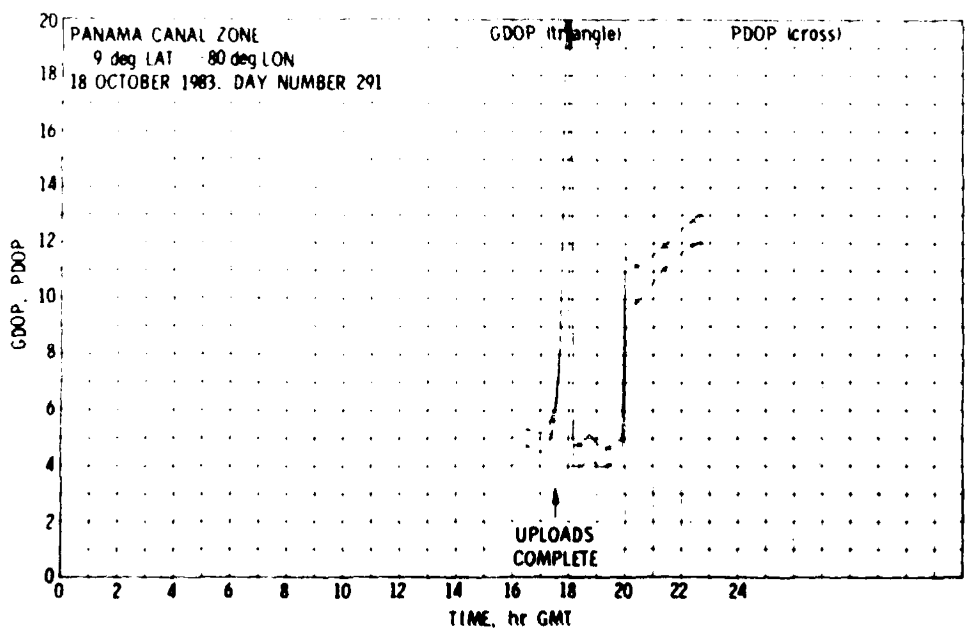

Figure 9. Four-Satellite GDOP, PDOP

In Alaska, it is the final period, as shown in Figure 10, which provides almost 2 hours of good gemetry after the uploads. Today this period begins about 7:30 in the morning local time, but as we know, constellation times move forward about 4 minutes per day, or 2 hours per month. Figure 11 illustrates how this fact may affect testing. For example, in Alaska in the middle of February, tests needing good geometry can begin at midnight.

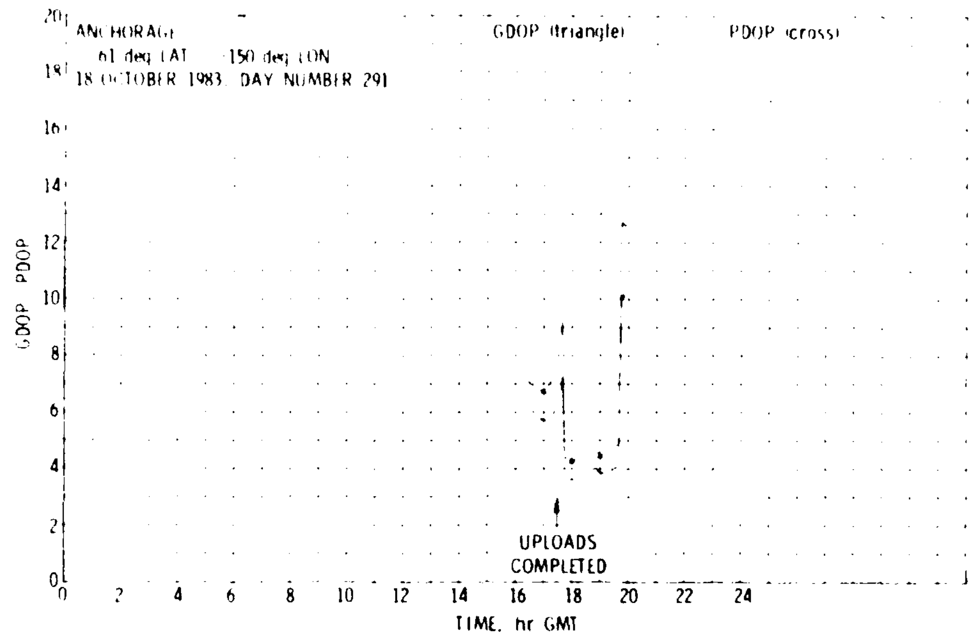

Figure 10. Four Satellite GDOP, PDOP

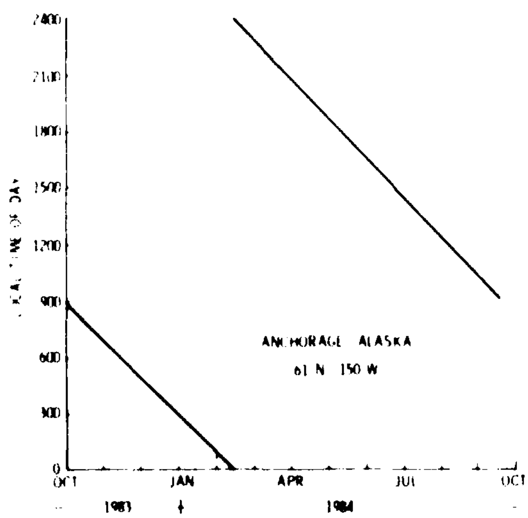

Figure 11. Beginning Time of Good Satellite Geometry

The development, test, and evaluation field tests are being conducted in the southwest United States (Figure 12). Aircraft and ground host vehicles, with which most of the field testing has been carried out so far, are tested at the U.S. Army Yuma Proving Ground (YPG) in the southwestern part of Arizona. Fixed wing aircraft, when tested at Yuma, have been staged out of the Naval Air Facility near El Centro, California. Helicopters are flown out of the Laguna Army Air Field at YPG.

Testing at sea, involving the carrier and submarine host vehicles, is just beginning; it is at the Navy's SOCAL ranges which lie between San Diego and San Clemente Island (Figure 13). The Naval Ocean Systems Center (NOSC) has been tasked to develop and operate the SOCAL test range in support of GPS phase II testing of user equipment. In doing so, NOSC has upgraded some of the range instrumentation hardware, has developed entire new software for data reduction and for trajectory reconstruction, and has adopted new procedures to assure instrumentation accuracy.

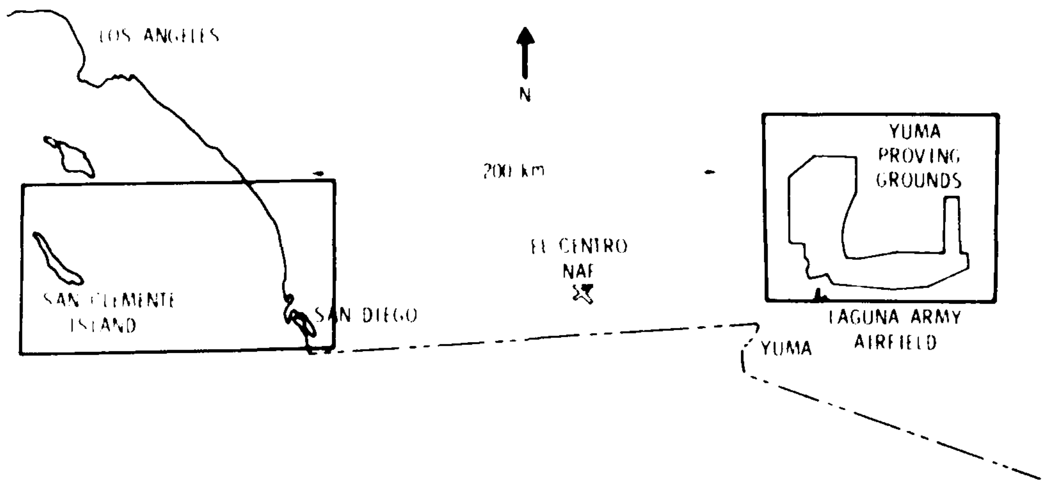

Figure 12. GPS DT&E Test Locations: Phase II UE

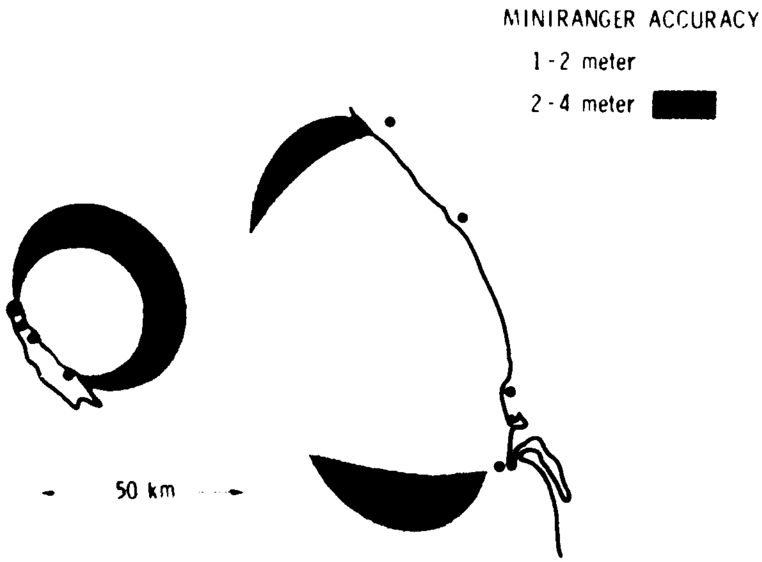

Figure 13. SOCAL Test Range, San Diego, San Clemente Island

The reference trajectory provided by the SOCAL range, when GPS testing is performed aboard the aircraft carrier at sea, is based upon the Mini Ranger IV System. It is a multilateration system with four reference stations (transponders) located on the mainland shore, from San Diego North to Camp Pendleton, and another set of four reference stations located on San Clemente Island. These transponders are interrogated by a receiver/transmitter aboard the ship. The ranges from the receiver/transmitter to the reference stations are recorded aboard the ship; these are the primary data output. A ship trajectory is generated in real time aboard the carrier; ship's location can be called up and displayed upon operator request. The ship position solution uses roll, pitch, and heading information which are transmitted from the ship's own instrumentation; this attitude information is also recorded for use in post test trajectory reconstruction.

A Kalman filter trajectory reconstruction program is used post test, based upon recorded ranges and ship altitude information to develop ship position and velocity as a function of time. The SOCAL range quotes an accuracy of from 1 to 4 meters for this system, depending upon geometry. Figure 13, which is based upon SOCAL developed geometry, also contains my own estimate of the locations at which accuracies better than 2 meters can be achieved, and also where 2 4 meters can be achieved. The SOCAL

accuracy estimates are based upon a number of tests in which the same target was tracked by the Mini Ranger system and by theodolites from a precisely known shore position.

All test control is performed from aboard the carrier. The ship's captain, of course, is in complete operational command; the GPS test team leader is aboard the ship and has available the real time Mini Ranger trajectory and the data from the GPS displays.

At the end of each test, the logs, the GPS tapes, and the Mini Ranger data tapes with ships attitude information are all transported to San Diego. At the NOSC computers there, the Mini Ranger data are processed to provide an improved trajectory. The GPS navigation solutions are transformed to the local (Mini Ranger) coordinate system, and the GPS position and velocity difference from the Mini Ranger solution are plotted. Also plotted are GPS receiver channel and set status, presenting a picture of the operations of the set over time.

GPS user equipment development tests aboard the submarine are conducted on the 3 d acoustic range which is located, as shown in Figure 14, near the northeast part of San Clemente Island. The reference trajectory is derived from data collected from four hydrophones located on the sea bottom, which pick up and transmit to a control station on San Clemente Island the time of receipt of acoustic signals from a pinger mounted on the bottom of the submarine hull. The pinger sends out one pulse per second; the timing is precisely controlled by a rubidium clock on the submarine. The arrival times are used in real time at the control station to develop an approximate submarine trajectory. They are also processed after the test using a Kalman filter implemented upon the NOSC computer. NOSC quotes an accuracy of 2 to 8 meters after acoustic range. Figure 14 shows estimates of the areas in which, respectively, 2 to 4 meter and 4 to 8 meter accuracy can be achieved. Please note on Figure 14 that the coverage is less in the northeast direction; also note that the assymetries in the accuracy regions are a consequence of the fact that the hydrophone closest to the shore is at a shallower depth than the other three hydrophones. Good accuracy on the 3 d acoustic range requires an accurate sound velocity profile. NOSC uses seasonal and monthly profiles augmented by daily sound velocity measurements through the surface layer (a few hundred feet). Depending upon submarine operational conditions, the logs generated onboard from a test and the GPS tapes are taken daily, or perhaps even weekly, to San Diego. There,in the same way as in the case of the aircraft carrier, GPS navigation data and status plots are prepared.

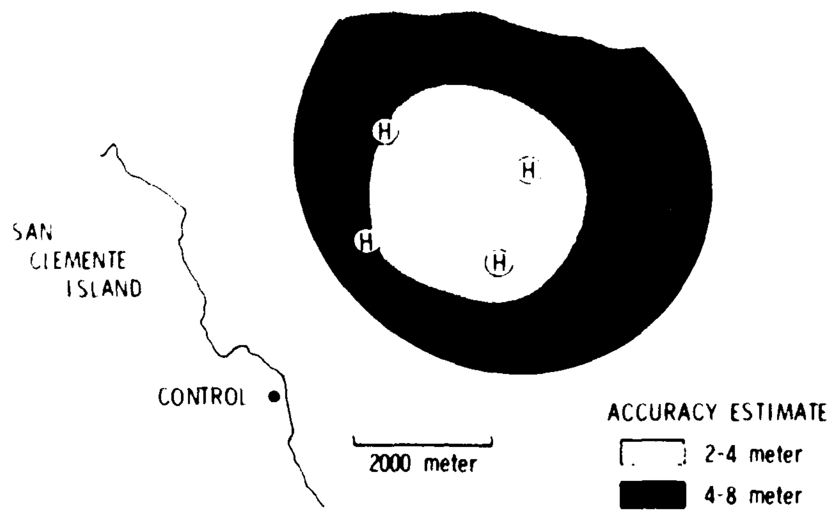

Figure 14. SOCAL 3 d Acoustic Range

During a submarine test, the captain is in complete control of the submarine movements. Usually a representative of the test team leader will be aboard. He will direct the set operator. The test team leader will usually be on San Clemente Island at the control station; he will have available the real-time 3 d trajectory. Communications are maintained between the control station and submarine by either or both radio and underwater telephone. The test team leader can advise his delegate as to the continuing test objectives. After the quick look package (consisting of logs, navigation differences, trajectory position and velocity, and GPS status) has been prepared by NOSC, all the quick look material is reviewed by the data analysis working group. Normally, this includes representatives from the NOSC range, the test team, the participating test organization, and the Joint Program Office; usually the UE

accuracy estimates are based upon a number of tests in which the same target was tracked by the Mini Ranger system and by theodolites from a precisely known shore position.

All test control is performed from aboard the carrier. The ship's captain, of course, is in complete operational command; the GPS test team leader is aboard the ship and has available the real time Mini Ranger trajectory and the data from the GPS displays.

At the end of each test, the logs, the GPS tapes, and the Mini Ranger data tapes with ships attitude information are all transported to San Diego. At the NOSC computers there, the Mini Ranger data are processed to provide an improved trajectory. The GPS navigation solutions are transformed to the local (Mini Ranger) coordinate system, and the GPS position and velocity difference from the Mini Ranger solution are plotted. Also plotted are GPS receiver channel and set status, presenting a picture of the operations of the set over time.

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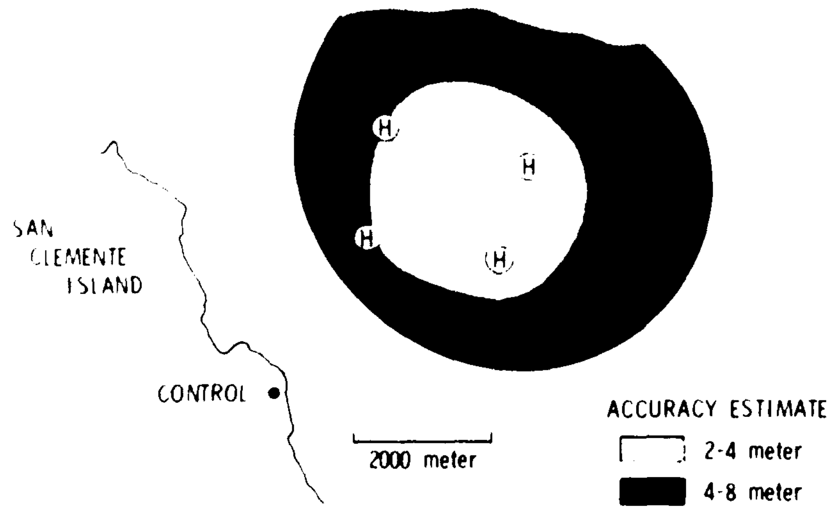

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contractor is invited to participate also. The findings of this data review are used in planning succeeding missions and are also included in the data pack which is sent to the JPO, UE contractor, the participating organization and the data analysis contractor. A major function of the data analysis team in reviewing the quick look package is to identify: (1) Any periods in which the range trajectory is invalid; (2) Any periods in which the GPS data are invalid, and if possible, the reasons for this invalidity; (3) The test segments which will be analyzed by the data analysis contractor.

On 15 September, a combined GPS/submarine 3 d range checkout test took place. Figure 15 shows the intended submarine track; it also shows the profile actually sailed. What happened was that the submarine encountered small boat traffic during each of the two turns at the south end of the 3 d range. In one case, the small boats were fishermen, and the second case, they were pleasure craft. There was a computer interface problem early in the test, resulting in loss of 3-d range data early in the test and also in a timing discrepancy which had to be straightened out later. A procedure problem aboard the submarine appeared to result in an improper antenna connection. The GPS set had two periods in which it is known to have operated correctly, another period in which it is known to have been operating incorrectly, and a fairly long period in which (because of the loss of 3 d range data) the operating condition of the set is unknown. All of these situations are typical of a checkout test, and corrective actions were identified. In particular, a patrol boat will be provided to keep the range clear.

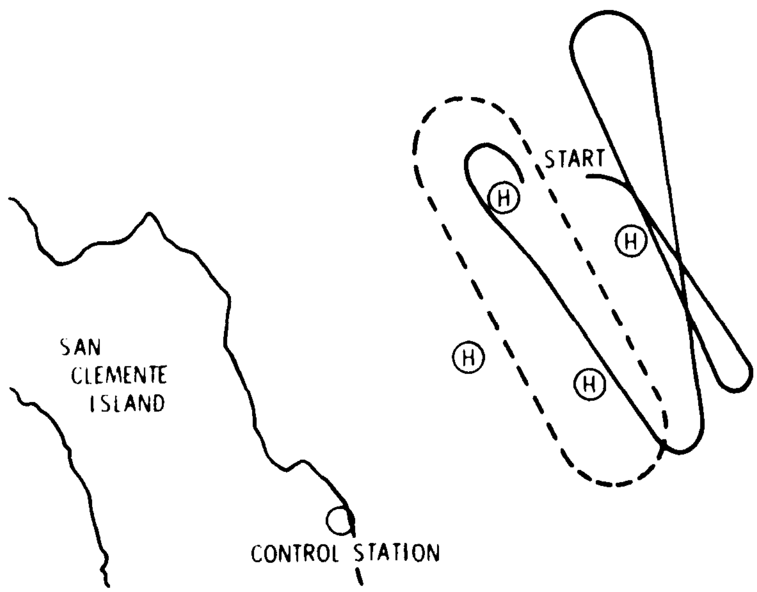

Figure 15. System Checkout: SSN, GPS, 3 d Acoustic Range, 15 September 1983

Most of the GPS user equipment testing so far has taken place at Yuma Proving Ground with DT&E host vehicles, which are a C 141 aircraft and two M 35 trucks (one for each contractor). These provide supplies and full DT&E instrumentation of the set. The trucks and the aircraft are equipped with telemetry, sending GPS data down in real time.

GPS tests have been conducted at the U.S. Army Yuma Proving Ground for the better part of a decade. The Yuma range (Figure 16) has available a large range controlled air space, excellent laser tracking capability, facilities for controlling two simultaneous missions, and computational support for post flight data reduction. Because Yuma is located in a desert, few tests are postponed because of weather, and the clear atmosphere gives high confidence in routine use of laser tracking from ground level to high altitude (laser trackers cannot penetrate clouds).

Shown in Figure 16 are the locations of the six laser trackers at Yuma Proving Ground. The tracking accuracy is estimated as from 2 to 3 meters for single laser solutions. Also shown in Figure 17 is my own estimate of the regions in which, respectively, 2 meter and 2 3 meter accuracy can be achieved. Figure 17 shows the PDOPs which exist at Yuma with the current satellite constellation. Note that there is about 1 3/4 hour of good geometry time available after the completion of satellite uploads. After Navstar 8 sets, there is an additional 1 1/2 hours during which the PDOP is greater than the availability specification value; during this period, performance evaluation is inappropriate, but such tests as checking set functions can readily be carried out.

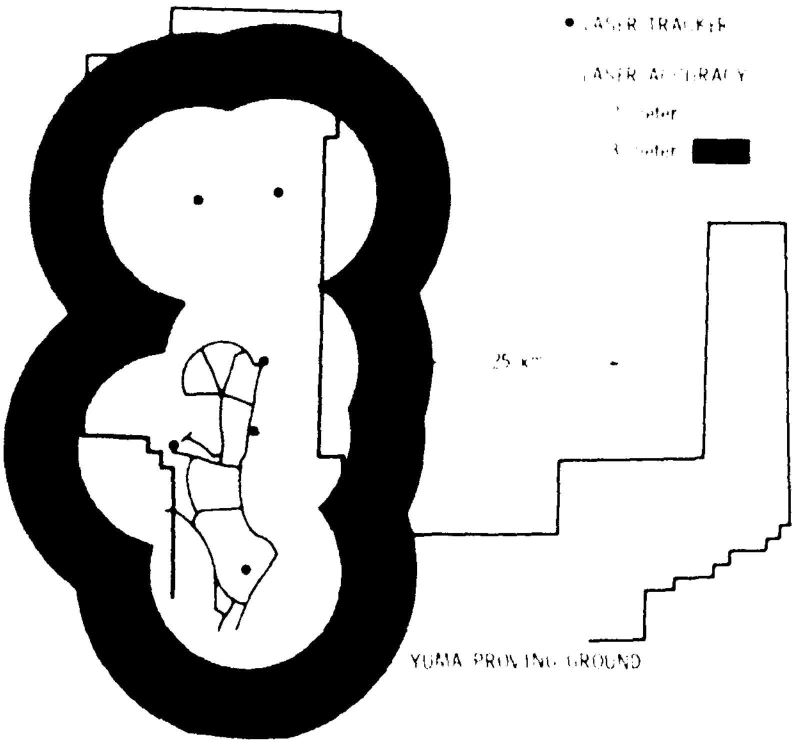

Figure 16. Yuma Proving Ground Facilities

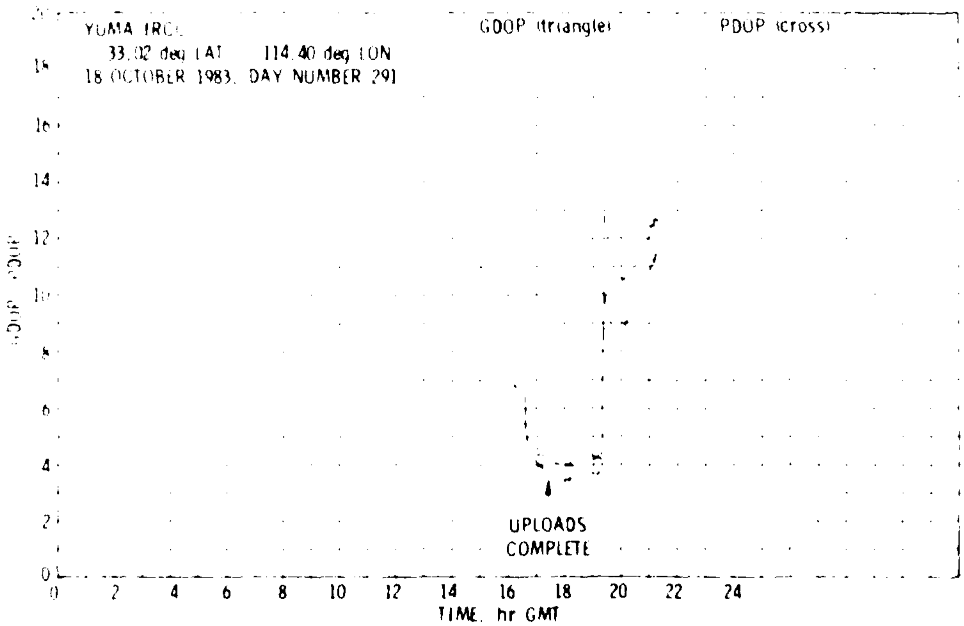

Figure 17. Four Satellite GDOP, PDOP

Test operations at Yuma are built around a real time system for control, data collection, and displays. In Figure 18, which has too much information on it, we first notice the capability for the two completely separate missions in two separate mission control centers. Each one has five cathode ray tube displays on which a variety of data can be presented.

During a mission, a control center may have as many as four different contollers and several passive observers:

1. The test team leader has a console. He is in charge of the mission and can communicate with any other test participant.

2. A YPG employee directs the aircraft. He communicates with the pilot, and uses a display of the intended trajectory and the actual trajectory and gives instructions to the pilot as to turns and altitude changes.

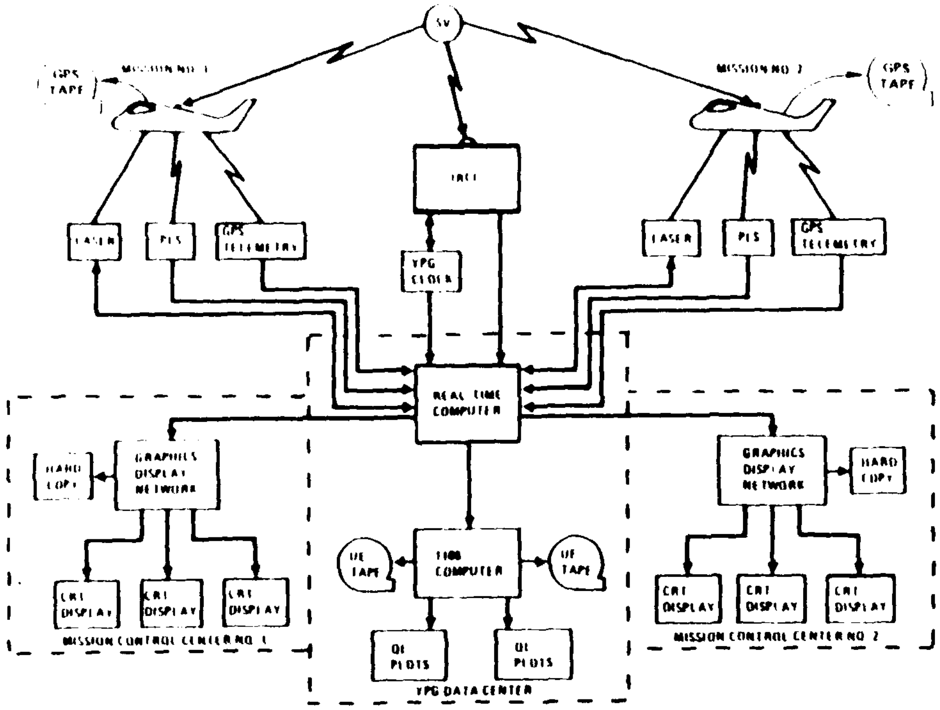

Figure 18. YPG Real Time Test Operations

3. Another range employee is the instrumentation controller. He is responsible for the correct operation of the telemetry equipment, for the operations of the lasers, and any other instrumentation which is in use. He is capable of removing a laser from consideration as the source of the RTE (real time trajectory estimate). He can also require any instrument to be the RTE solution.

4. Normally, a UE contractor representative occupies one of the consoles and can communicate with the set operator onboard the aircraft.

Observers have the opportunity to watch any one of many possible displays. These include differences between the telemetry GPS navigation solution and the RTE either in position or velocity; also included is the capability to watch the GPS status and general figure strengths.

All data recorded on the GPS onboard tapes are also sent by telemetry to the real time computers in the mission operations center. The entire data stream is saved; some of the data are stripped off and used in the real time displays.

The raw range, azimuth, and elevation data from each of the six lassers are sent 20 times per second to the real time computer. Calibration and refraction corrections are applied, and a separate trajectory is generated for each laser. The trajectory is computed by a fixed gain retrospective filter. "Retrospective" means that the solution which comes out of the filter is 1 second earlier in time then the latest data into the filter.

The real time trajectory estimate (RTE) is one of the single laser solutions. Usually, the selected laser is the laser closest to the aircraft, so long as that laser indicates that its data are valid. Immediately after a mission YPG, using telemetry data, generates a data pack consisting of plots of the aircraft trajectory position and velocity, GPS RTE differences (these are illustrated in Figures 19 and 20), and GPS status; all are plotted in 1/2 hour segments. The entire YPG data pack as well as a merged tape containing GPS, laser tracker, and IRCC data are ready for analysis within 4 to 6 working hours after the end of a mission. Sometimes too, they are generated on overtime immediately after a mission, even in the very early hours of the morning.

Sometime ago, I decided almost casually to use 24 June 1983 as an example of testing at Yuma, simply on the basis that it seemed that quite a few tests had been conducted that day. Figure 21 represents the pre test planning status. A major constraint was the fact that the site 4B laser was being repaired; the azimuth servo motor was out because of a coolant leak. This laser is the one which tracks ground vehicles on the dynammeter course. There could be no instrumented tests using the M 35 truck. Consequently, the truck and its one channel set were set up for a special test, to check the satellite selection algorithm. This required use of Navstar 1 (the satellite with the backup crystal clock) so that navigation performance *per se* was not a test objective.

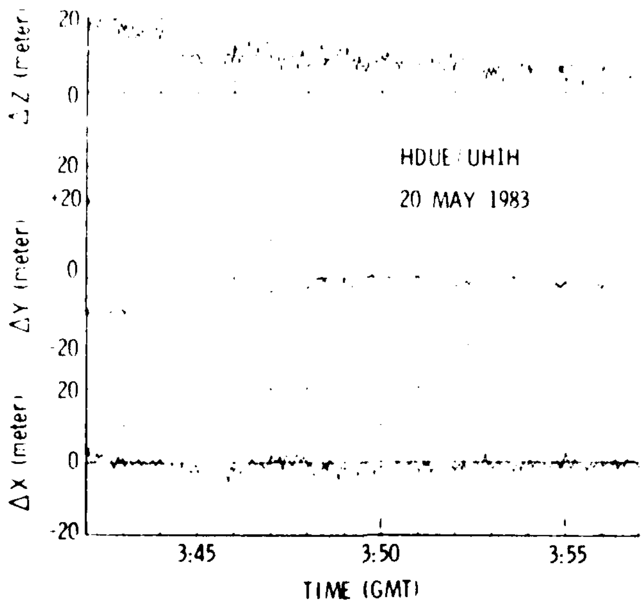

Figure 19. Position Differences: GPS RTE

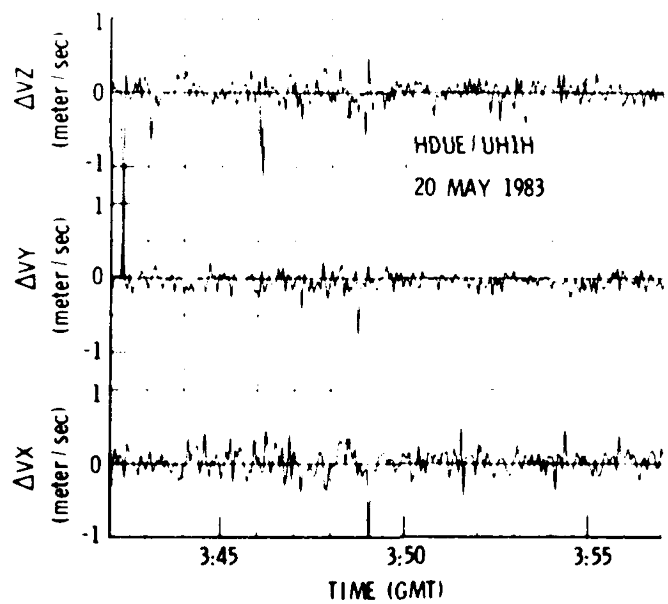

Figure 20. Velocity Differences: GPS RTE

A static shakedown test was scheduled for another one channel set integrated with the M 60 tank.

Three different sets were to be flown aboard the C 141 aircraft, all with the basic objective of determining navigation performance under dynamic conditions. This aircraft was to fly racetrack profile at an altitude of 6200 meters; two thirds of the racetracks were to be flown with 30° bank turns, categorized as moderate dynamics, while the rest were to have 60° bank turns high dynamics. The real time mission's control rooms were dedicated to the two 2 channel sets, one for each contractor. The two rooms are at least a 100 foot walk apart, and one is in an additionally controlled area, so that the two competing contractors were effectively separated.

The results of the day's operation were a mixture of success and partial success. First of all, the physical operations were all completely nominal. Pre test and post test briefings were held as scheduled, and the aircraft flew as planned, going

[illegible] moderate dynamic racetracks and 6 high dynamic ones. Both kinds of racetracks are shown in Figure 22, which covers half an hour of flight near the end, [illegible] MT. Figure 21 is a summary of the results.

- SATELLITES
  - 0115 LAST UPLOAD
  - 0306 NAVSTAR 4 SETS
- RANGE INSTRUMENTATION
  - SITE 4E LASER DOWN (repair occasioned by cooling water leak)
- PLANNED MISSIONS
  - C-141 WITH 3 SETS (high dynamics)
    - MAGNAVOX 2 CHANNEL (telemetry)
    - COLLINS 2 CHANNEL (telemetry)
    - COLLINS 5 CHANNEL
  - M-35 TRUCK (static – satellite selection algorithm)
    - COLLINS 1 CHANNEL
  - M-60 TANK (static – checkout)

Figure 21. A GPS Test Day at YPG 24 June 1983

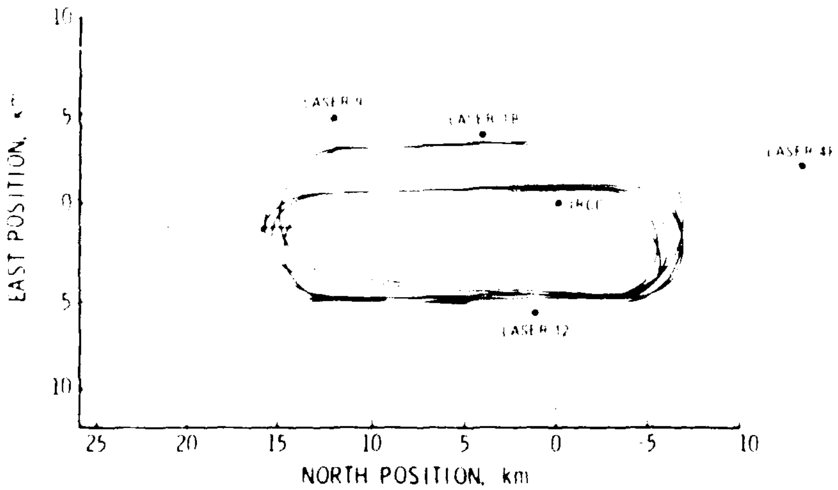

Figure 22. C-141 Aircraft Trajectory 24 June 1983, 0020 through 0250Z

- SATELLITES
  - GROUND TRUTH ACCEPTABLE: MAXIMUM RADIAL ERROR - 10 meter
- RANGE INSTRUMENTATION
  - SITE 12 LASER HAD ATTENUATOR PROBLEM: REMOVED
- RESULTS
  - BRIEF DROPOUTS IN TELEMETRY RECEPTION
  - DROPOUTS IN GPS SIGNALS (masking)
  - GOOD DATA FROM ONE AIRBORNE RECEIVER
  - INTEGRATION DIFFICULTIES NOTED WITH TWO AIRBORNE RECEIVERS: DIAGNOSTIC DATA COLLECTED
  - INTERFACE PROBLEM IDENTIFIED ON TANK
  - SATELLITE SELECTION ALGORITHM OK

Figure 23. A GPS Test Day at YPG - 24 June 1983 Summary

The satellites and control segment performed well within specifications; the largest radial error measured at the IRCC receiver (we'll talk more about that later), was 10 meters, and most of the time the errors were a good deal less.

One of the remaining lasers had an attenuator problem. It continued to operate, but the instrumentation controller removed it as a possible RTE source.

As expected, there were some GPS signal dropouts; these occurred in turns and were attributed to masking of the antenna by aircraft structure.

There were also some brief telemetry dropouts. These are also believed to have been caused by masking. The consequences of the dropouts were deemed minor in that the decision was made to do all possible post flight data processing with recorded telemetry.

There was good data from one of the airborne sets. At the post mission quick look data analysis meeting, the entire flight was identified for performance evaluation, and 38 different flight segments were selected.

Each of the other two airborne receivers experienced problems. These were written up as deficiencies during the quick look data analysis meeting; performance evaluation was ruled out.

The satellite selection algorithms worked. Data collection was prematurely halted on the tank set because of an interface problem.

So we had a busy day. Having two lasers out was a rare event, and the site 12 lasers were back in operation the next day.

Since we have already referred at least twice to analysis of the field test data, it is in order to talk specifically about data analysis procedures. For the Joint Program Office, data analysis is under the Data Analysis Working Group (DAWG). The Manager of that group is Sqn. Lt. Brian Sposen, RAF. He is responsible for, among many other things, planning all data analysis and coordinating that planning with all participating test organizations, for a data management system to allow cross-reference from test objectives to test results and test reports, and for assessment of quick look data, maintenance of the data base, and tracking the achievement of objectives. He is assisted in data base management and data processing for performance evaluation by a data analysis contractor.

Figure 24 sketches the data analysis procedures which directly apply to field test results. We should emphasize the important role played by test planning and real time monitoring of the test. At Yuma, the capability to monitor by telemetry the set operation in real time allows the Data Analysis Working Group representative to watch the whole mission. He is then well prepared to lead the quick look mission assessment, which takes place as soon as the Proving Ground has the trajectory, difference, and GPS status plots ready. (Let me, please, add a personal note. A major benefit from observing a mission in real time is that the events pass by at one second per second. You cannot skim over a half hour plot with just two looks. You might overlook a little glitch on a plot, but when you see it happen and then happen again under a similar set of circumstances, you are strongly motivated to understand what is going on.)

- REAL TIME
  - MISSION PREBRIEF
  - SET OPERATIONS AND FUNCTIONS
  - POST MISSION DEBRIEF
- QUICK-LOOK
  - ANOMALY IDENTIFICATION
  - DATA VALIDITY
  - TEST SEGMENTS FOR ANALYSIS
- PERFORMANCE ASSESSMENT
  - DATA ANALYSIS CONTRACTOR
  - ALL IDENTIFIED SEGMENTS
  - TEST RESULTS DATA BASE SET TYPE, CONTRACTOR, DYNAMICS, HOST VEHICLE

Figure 24. Data Analysis Procedures for Field Test Results

The quick look analysis is a Data Analysis Working Group activity led by a DAWG representative. Participants include the JPO, the test range, the participating test organizations and the data analysis contractor. We always try to have the participation, too, of the field engineer of the user equipment contractor. The procedure is first to review all test logs and all plots and pick out all anomalies, determine whether they are familiar or new, and attempt to identify at least the circumstances. We look at the laser (or Mini Ranger or 3 d acoustic) data provided by the range to determine whether any segments should be discarded on the basis of questionable reference trajectory accuracy and to help subsequent analysis by pointing out range data gaps and transient conditions. A major and time consuming task is to select and categorize the various test segments which the data analysis contractor will treat as essentially homogeneous. Segments are categorized by dynamic conditions and by test objectives (for example: general navigation or time to first fix). All periods with invalid data of any kind are specifically identified for exclusion. Thus, the initial selection decisions are made in the field promptly, and by program office and test organization representatives. They are not made by the data analysis contractor.

The data analysis contractor receives the merged tape with GPS, RTE, and IRCC data, the entire data pack, and the processing instructions from the DAWG. He processes all indicated segments and for navigation segments, computes mean and rms errors in position and velocity. He prepares a standard set of plots for each segment. For summary purposes, he combines segment data into mission and ensemble results and enters these into his data base. The plots and data base can be called up from authorized remote terminals, located at the Joint Program Office, at Yuma, and at NOSC in San Diego.

Another aspect to GPS field testing is the performance of the control segment and the space segment. When we consider the navigation accuracy achieved in a test, we compare the output of the set with the trajectory determined by range instrumentation. Any error introduced by, for example, an unstable satellite clock or by an imprecise prediction of satellite ephemeris is directly transformed into position and velocity errors, and they are included. The data analysis contractor does <u>not</u> correct for spare segment and control segment errors.

The satellite data message is a <u>prediction</u> made (currently once per day) by the control segment of what the ephemeris and clock parameters will be. The control segment Kalman filter also estimates, once every 15 minutes, what are the current satellite location and clock states. For quality control, the control segment compares its predicted values with those it currently estimates and (for ease of interpretation) expresses the comparison in terms of its best estimate of the pseudo range errors which would be experienced by a user at Yuma (or any other desired location several can be calculated at once). Figure 25 is an example of the user ranging error (URE) plots routinely issued. In this figure we note first that UREs on this day are in the small to 25 meter range when using the data messages prepared the day before. We see the two sets of new uploads, an hour apart. We see subsequent UREs of the order of 1 to 2 meters through the rest of this plot, covering much of the Yuma four satellite visibility period. The control segment here considers that upload to be of acceptable quality; if the URE threatened to exceed 4.5 meters, a "contingency upload" would be prepared.

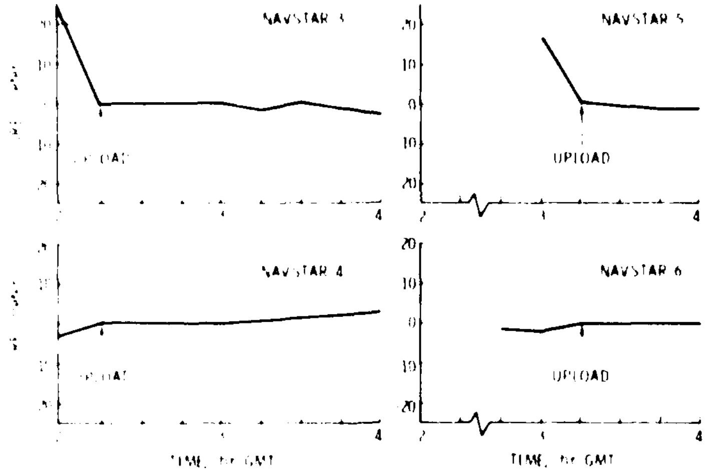

Figure 25. Control Segment Estimates of User Ranging Error 25 May 1983

A conceptual problem with this procedure is that it is entirely based on data internal to the control setment itself and, by the nature of Kalman filters, the UREs would be zero if the monitor stations were not providing any data at all! (It is really not necessary to print out that the control segment would highlight any such situations.)

At Yuma, there is a separate monitor. A well-calibrated, heavily instrumented, and continuously maintained receiver is located in the middle of the range at a well known survey point. During testing at Yuma, it monitors all visible satellites and, at an 18 second data interval, inputs a so-called ground truth solution. This is a close approximation to what a perfect GPS set would give at Yuma. The continuous lines on Figure 26 are outputs from this receiver, showing the difference between its navigation solutions and its known location. Before the upload at 3:15, we see biased and drifting solutions and after the upload, we see that the drifts were effectively eliminated. The biggest error left is an altitude bias of about 5 meters. The discrete points in Figure 26 were computed by transforming the UREs (Figure 25) into x, y, z coordinates. The agreement between the two different sets of data is excellent. The vertical lines are a conservative estimate of the expected magnitude of the difference between the two methods of estimating space segment/control segment errors, and what we see supports the validity of both methods. Thus, we are not only including the performance of the space and control segments in our evaluation of user equipment accuracy, we are also constantly assessing that performance.

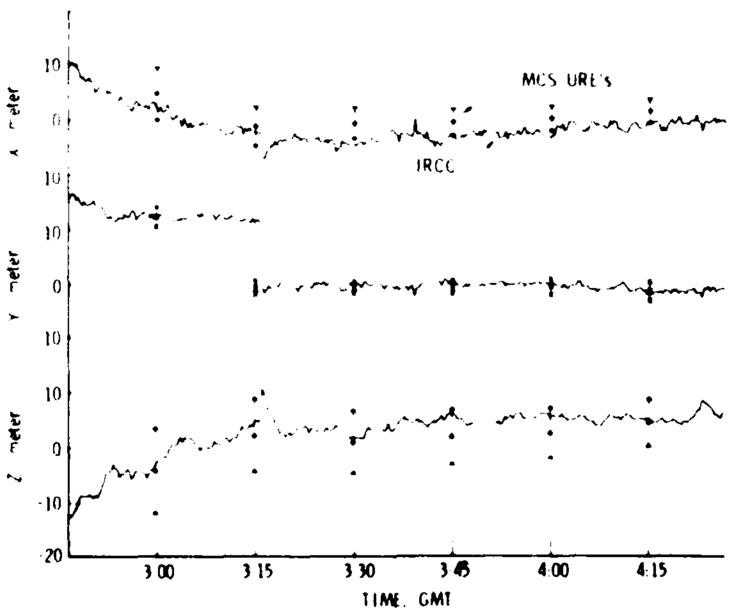

Figure 26. Ground Truth Comparison 25 May 1983

Figure 27 is a count of the tests conducted at Yuma as of early September; these are 135 tests for which data packs have been distributed.

As of today, we have not completed the planned DT&E field testing; we are heavily into SIL and MOD center tests; we have begun operational readiness testing with Army man packs. Some very preliminary results taken from the data base maintained by the data analysis contractor indicate that the sets tested are not yet mature. They suggest, however, that the level of achieved performance is within specifications.

- 84 DAYS WITH TESTS
  - 57 WITH 1 TEST
  - 10 WITH 2 TESTS
  - 11 WITH 3 TESTS
  - 5 WITH 4 TESTS
  - 1 WITH 5 TESTS

Figure 27. Field Tests at Yuma and El Centro through 6 September 1983

Finally, as noted in Figure 28, the GPS test program is well underway, and exercises all three program segments. It is capable of providing data to support the comprehensive evaluations of the competing user contractor sets and determining the set capabilities and the GPS military utility and operational suitability.

- TEST PROGRAM EXERCISES
  - SATELLITE SEGMENT
  - CONTROL SEGMENT
  - USER SEGMENT
- COMPREHENSIVE, COMPETITIVE EVALUATION
  - CAPABILITIES
  - MILITARY UTILITY
  - OPERATIONAL SUITABILITY
- HEAVILY UNDERWAY

Figure 28. Summary of GPS Test Program

The discussion which followed this presentation appears in classified publication CP 344 (Supplement)

POTENTIAL IMPACT OF NAVSTAR GPS ON NATO TACTICAL OPERATIONS

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SUMMARY

The Navstar Global Positioning System created when the United States Deputy Secretary of Defense directed that separate efforts by the U.S. Navy and the U.S. Air Force to develop a satellite-based navigation system be combined into a single program and placed under the executive control of the USAF. In 1978, at the invitation of the United States, nine NATO nations joined the project by establishing a NATO team at the Navstar Joint Program Office. This paper outlines NATO involvement in the program, highlights some of the unique, operationally significant features of the system, and describes a few representative operational scenarios where the benefits of Navstar would be particularly useful.

INTRODUCTION

In 1969 the NATO Military Committee published a navigation requirements document (MC 139) which outlined the required characteristics of navigation systems for all military applications. These characteristics included the requirement for world wide operations in any weather condition, at all times of the day or night, and protection to the maximum extent possible against destruction, jamming or unauthorized use. In addition, these systems were to make use of a common frame of reference.

Although in 1969 there was no single candidate system on the horizon to meet these requirements, the preceding characteristics provide a very accurate description of the Navstar Global Positioning System as far as they go. Of course, Navstar has an even longer list of attributes, including passive operation, extreme accuracy, and the capacity for an unlimited number of users. The system promises to provide navigation and positioning information of unprecedented accuracy, and if adopted widely throughout NATO should lead to improved force coordination and a considerable reduction in navigation support costs. This paper will outline NATO involvement in the Navstar project and will then discuss a few scenarios in the NATO environment where Navstar promises to provide significant benefits.

NATO INVOLVEMENT

NATO involvement in the Navstar Global Positioning System was made possible by an offer from the United States to all NATO nations to participate in the Full Scale Engineering Development phase of the program. This early involvement by so many nations in a major U.S. development program was unique. In 1978, nine nations agreed to participate in the program and a multi-national Memorandum of Understanding was prepared and signed by the National Armament Directors. A NATO Navstar Steering Committee comprising national principal representatives from each of the participants was established to ensure effective implementation of the MOU and to manage the activities of a NATO team at the Joint Program Office.

The NATO team of 12 officers was established at the U.S. Joint Program Office in the fall of 1978 under the leadership of a NATO Deputy Program Manager. Members of the team were fully integrated into the Program Office in management, engineering and logistic support positions. The purpose of the team is to contribute to the U.S. development program and to establish a flow of information back to the nations to assist the nations in reaching decisions on the eventual employment of Navstar. This information flow is government to government, is controlled by the NATO DPM, and is coordinated in each country by the national principal representative.

Recently, it has become apparent that NATO involvement beyond the formal Phase II portion of the program is essential if NATO nations are to be kept fully informed on the evolution of the system. As a result the Memorandum of Understanding has recently been revised to ensure NATO participation until the 1988 time frame. This revised MOU is expected to be signed by the National Armament Directors in October 1983.

PRECISE TIME

Navstar is advertised and widely thought of as a positioning system. However it is much more than that. To begin with, it offers not only very precise positioning information, but also very precise velocity and time. The potential of Navstar as a time source is often forgotten in discussions with the various user communities. However, the usefulness of a time source accurate to microseconds or even nanoseconds is becoming increasingly apparent with the proliferation of sophisticated time dependent communication, identification, reconnaissance, and precision location systems.

PASSIVE OPERATION

Another aspect of Navstar considered to be of overwhelming importance is the fact that, to the user, the system is completely passive. As a result, when one evaluates the contribution of Navstar to a given military objective, it is not enough to simply note the accuracy improvements over other current and proposed avionics fits. Navstar is the only system that can provide acceptable performance in a completely passive mode. And as one considers the threat, particularly in Central Europe, it is apparent that an aircraft that can perform its mission passively will have a much higher survival rate than one which is radiating a broad spectrum of RF energy.

POTENTIAL IMPACT OF NAVSTAR GPS ON NATO TACTICAL OPERATIONS

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SUMMARY

The Navstar Global Positioning System created when the United States Deputy Secretary of Defense directed that separate efforts by the U.S. Navy and the U.S. Air Force to develop a satellite-based navigation system be combined into a single program and placed under the executive control of the USAF. In 1978, at the invitation of the United States, nine NATO nations joined the project by establishing a NATO team at the Navstar Joint Program Office. This paper outlines NATO involvement in the program, highlights some of the unique, operationally significant features of the system, and describes a few representative operational scenarios where the benefits of Navstar would be particularly useful.

INTRODUCTION

In 1969 the NATO Military Committee published a navigation requirements document (MC 139) which outlined the required characteristics of navigation systems for all military applications. These characteristics included the requirement for world wide operations in any weather condition, at all times of the day or night, and protection to the maximum extent possible against destruction, jamming or unauthorized use. In addition, these systems were to make use of a common frame of reference.

Although in 1969 there was no single candidate system on the horizon to meet these requirements, the preceding characteristics provide a very accurate description of the Navstar Global Positioning System as far as they go. Of course, Navstar has an even longer list of attributes, including passive operation, extreme accuracy, and the capacity for an unlimited number of users. The system promises to provide navigation and positioning information of unprecedented accuracy, and if adopted widely throughout NATO should lead to improved force coordination and a considerable reduction in navigation support costs. This paper will outline NATO involvement in the Navstar project and will then discuss a few scenarios in the NATO environment where Navstar promises to provide significant benefits.

NATO INVOLVEMENT

NATO involvement in the Navstar Global Positioning System was made possible by an offer from the United States to all NATO nations to participate in the Full Scale Engineering Development phase of the program. This early involvement by so many nations in a major U.S. development program was unique. In 1978, nine nations agreed to participate in the program and a multi-national Memorandum of Understanding was prepared and signed by the National Armament Directors. A NATO Navstar Steering Committee comprising national principal representatives from each of the participants was established to ensure effective implementation of the MOU and to manage the activities of a NATO team at the Joint Program Office.

The NATO team of 12 officers was established at the U.S. Joint Program Office in the fall of 1978 under the leadership of a NATO Deputy Program Manager. Members of the team were fully integrated into the Program Office in management, engineering and logistic support positions. The purpose of the team is to contribute to the U.S. development program and to establish a flow of information back to the nations to assist the nations in reaching decisions on the eventual employment of Navstar. This information flow is government to government, is controlled by the NATO DPM, and is coordinated in each country by the national principal representative.

Recently, it has become apparent that NATO involvement beyond the formal Phase II portion of the program is essential if NATO nations are to be kept fully informed on the evolution of the system. As a result the Memorandum of Understanding has recently been revised to ensure NATO participation until the 1988 time frame. This revised MOU is expected to be signed by the National Armament Directors in October 1983.

PRECISE TIME

Navstar is advertised and widely thought of as a positioning system. However it is much more than that. To begin with, it offers not only very precise positioning information, but also very precise velocity and time. The potential of Navstar as a time source is often forgotten in discussions with the various user communities. However, the usefulness of a time source accurate to microseconds or even nanoseconds is becoming increasingly apparent with the proliferation of sophisticated time dependent communication, identification, reconnaissance, and precision location systems.

PASSIVE OPERATION

Another aspect of Navstar considered to be of overwhelming importance is the fact that, to the user, the system is completely passive. As a result, when one evaluates the contribution of Navstar to a given military objective, it is not enough to simply note the accuracy improvements over other current and proposed avionics fits. Navstar is the only system that can provide acceptable performance in a completely passive mode. And as one considers the threat, particularly in Central Europe, it is apparent that an aircraft that can perform its mission passively will have a much higher survival rate than one which is radiating a broad spectrum of RF energy.

COMMON GRID

Another significant benefit of Navstar is the ability to tie all users into a common grid, accurate to within 15 meters. The importance of operating to a common grid reference applies equally to the air, land and sea forces of NATO. In the airborne application it would allow much closer cooperation and greater effectiveness among the reconnaissance and attack elements of the Air Forces. In close air support missions it would enable forward air controllers to identify target positions to the support aircraft much more accurately. In naval operations it would provide the common grid for airborne, surface and sub-surface units. It is interesting to note that in early Phase I deployments with the U.S. Pacific Fleet, Navstar enabled the units to maintain grid lock to a far greater degree of accuracy than had ever been possible before. When one notes the benefits of common grid within the units of one country's armed forces, it becomes very clear just how valuable this characteristic would be when the forces of several nations are operating together.

APPLICATIONS

Airborne/Airmobile Operations

Trials conducted during Phase 1 of the program confirmed the capability of Navstar to make possible extremely accurate personnel and equipment airdrops. This should not surprise anyone - a navigation system promising accuracies of 15M in 3 dimensions should allow for very precise aerial delivery. The significance of the system lies in allowing deliveries of this accuracy in all weather, day or night, without visual reference. This is particularly relevant to clandestine operations where both the aircraft and the jumper could be equipped with Navstar.

Aerial Resupply

It can be anticipated that enemy interdiction of supply lines will force a heavy dependence on aerial resupply in some instances. Much of this resupply will occur in close proximity to the FEBA and therefore in a hostile environment for slow flying tactical transport aircraft. Survivability would be greatly enhanced if this resupply could be conducted under cover of darkness or adverse weather. Assuming the land forces are equipped with Navstar and in communication with the tactical airlift, and given the accuracy of Navstar, ammunition could be dropped to the artillery units, POL to the fuel dump and food to the mess tent.

Airmobile Operations

In airmobile operations, Navstar offers the potential to land at a predesignated landing zone without pre-positioned navigation or approach aids. Moreover, Navstar has the capability to allow operations from established facilities under conditions of absolute darkness and in extremely poor visibility. Trials conducted at Yuma Proving Ground during Phase I testing using the test constellation of satellites demonstrated the usefulness of Navstar in a Rel Nav mode. Landings were made with reference only to the Navstar-driven cockpit displays. Accuracies were in the order of 1-3 meters.

Additionally, in trials done earlier in the mountains surrounding Yuma, Navstar was found to provide sufficiently accurate vertical information to fly a type of terrain following profile. These trials used available stored map data and normal GPS operation. The actual flight paths flown agreed very closely with the theoretical results of earlier simulation runs. This capability should enhance the ability of tactical helicopter pilots to fly operational missions at night and in adverse weather. Given this sort of promising potential, future airmobile operations should be limited only by the imagination of the planning staffs.

Interdiction/Counter Air Operations

Under this generalized topic heading are included reconnaissance, interdiction and offensive counter air operations. These missions are all common to the extent that they require extended flight over hostile territory and they generally require the ability to find fixed targets at known coordinates. In the Central European environment, this implies both adverse weather conditions much of the time, and very sophisticated enemy air defences including active ECM.

It is in these mission areas that the passive nature of Navstar acquires such significance. Todays modern attack aircraft are capable of attacking fixed targets with high accuracy but to do this they often must radiate a significant amount of RF energy to accomplish the mission. In the words of one experienced fighter pilot, the attack aircraft resembles a huge searchlight on a dark night as it crosses into enemy territory. Terrain following radar, attack radar, radar altimeter and doppler all contribute to this energy transmission and all may be required to complete the mission successfully. However, they make the aircraft extremely vulnerable to enemy air defences.

With Navstar and INS on the other hand, the attack aircraft has two completely passive systems that are almost perfectly complementary in nature. Navstar provides the INS with frequent, highly accurate position updates thereby bounding the error buildup, while the INS provides Navstar the aircraft velocity, attitude, and rate-aiding to enable the bandwidth of the receiver to be kept very narrow, thereby reducing the effects of ECM. In close proximity to high value targets when Navstar may be swamped by jamming, the INS can take over in the short term with very little degradation of accuracy.

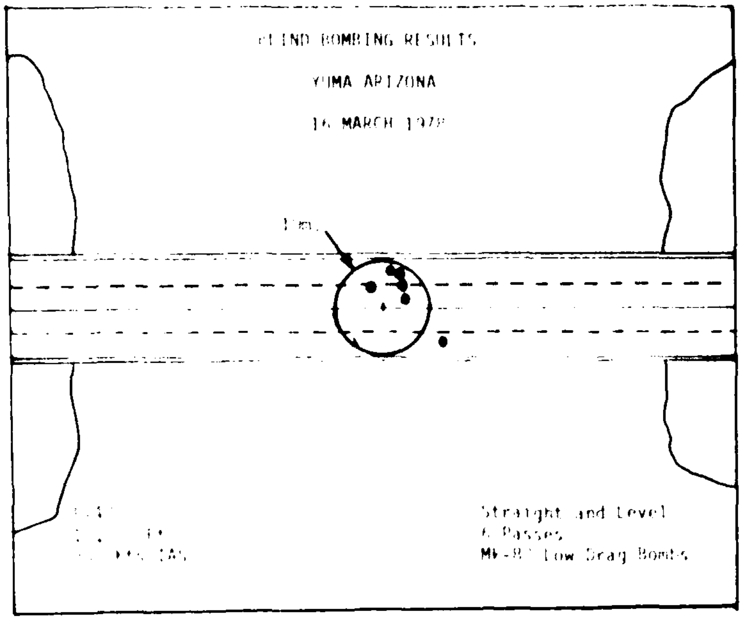


Figure 1

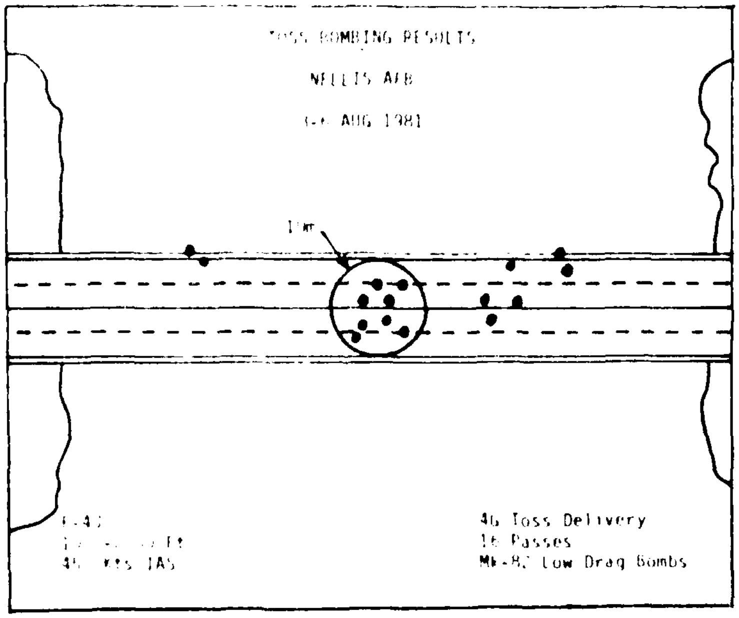


Figure 2

The bombing result shown at Figure 1 provides a good example of the weapon delivery accuracy possible with Navstar. These results were obtained in a 10,000 foot, straight and level delivery which although not representative of a typical NATO scenario, provides good evidence of the accuracy available from the system. Figure 2 shows results obtained in a 4-g toss delivery and they are equally impressive. Note again that these results were obtained with toss bombing from approximately 3-4 miles from the target. This too, greatly enhances survivability. With GPS, the "dumb iron bombs" have been given the approximate effectiveness of smart weapons.

For certain interdiction missions, the targets are not at fixed, known geographic points but are mobile. In these situations too, Navstar can play an important role. With the newer smart weapons such as the various cluster weapons currently being tested, the warheads are given some ability to discriminate amongst targets provided they are launched in the immediate vicinity of the targets. Whereas it is now necessary for the pilots to place electro-optical weapons in visual contact with the targets, Navstar could be used to blind launch the smart weapons, secure in the fact that when the weapons break out of cloud or fog they will be within a few meters of the closest approach to the target. This would also allow designers to use a sensor with much narrower field of view.

Anti Submarine Warfare

Turning now to the topic of anti-submarine warfare, the simple anti-submarine warfare scenario shown at Figure 3 will be used to illustrate the potential benefit of Navstar. This scenario shows an aircraft tracking a submarine using data from passive directional sonobuoys. Typically, this type of buoy provides bearing and doppler velocity data to the aircraft target tracking algorithm. Obviously, the objective is to achieve an accurate track on the target and attack, in this case, using a conventional homing torpedo.

Figure 4 shows the same scenario but this time indicates the main components of the attack error budget. It also highlights the vulnerability of the torpedo during the search phase prior to target acquisition. The first error component is the aircraft navigation system error. For current doppler or inertial based systems this error is time dependent, vary with aircraft maneuvers or sea-states and can accumulate very rapidly. The second, error component consists of geometric interbuoy errors where the buoy relationships are not those stored in the aircraft computer. The interbuoy errors are produced by the marked variability of sonobuoy ballistics and the drift of the buoys in the water. Experience has shown that there is little correlation of drift direction and speed between sonobuoys. These interbuoy errors can become very significant over a typical tracking period of 10 to 15 minutes. These errors are currently reduced by either flying to on-top one sonobuoy prior to an attack or by using a sonobuoy reference system. However, these techniques limit the tactical freedom of the aircraft and introduce other errors and vulnerabilities. GPS provides the potential to minimize all of these errors. Obviously, if the aircraft is fitted with a GPS receiver producing a bounded error in the order of 20 meters then, for this scenario, the aircraft navigation errors are effectively zero. To minimize the inter-buoy errors it is necessary to fix the position of each sonobuoy and update those positions regularly. The GPS satellite signals provide the capability to solve the sonobuoy tracking problem by implementing GPS frequency translators on each buoy.

Figure 5 is a simple schematic which illustrates the frequency translator principle. The translator, in this case on the sonobuoy, receives the signals from the visible GPS satellites. The L band signals are translated to S band and retransmitted with a pilot carrier. The aircraft acquires and tracks the carrier and translates GPS signals and so generates buoy positions and velocities. The buoy positions would be used to correct the interbuoy relationships and the velocity could be fed back to the sonobuoy processor to correct the target doppler velocity estimates.

Returning to the anti-submarine warfare scenario seen at Figure 6, this time with the errors reduced by GPS, it is possible to consider new developments in future ASW torpedoes. At present, because large attack errors are anticipated it has been necessary to develop weapons with the capacity to execute protracted searches for the target. During this search phase the torpedo is vulnerable to acoustical countermeasures and target maneuvers. If, using GPS, it is possible to minimize aircraft and buoy position errors to tens of meters then, it will be practicable to feed the target position, course and speed to the torpedo at release and so achieve a direct attack with only minimal search and increased probability of successful acquisition. In this way the GPS would significantly improve an operational capability.

L to S band frequency translators are already in use for missile tracking on the US Navy Trident program. Frequency translators will also be built and tested as part of the DoD GPS Range Applications Joint Program Office test program. These current translators are far too bulky and expensive for sonobuoy applications. However, projecting the current developments in electronic miniaturization and cost reducing production techniques, it should be feasible to produce low-cost translators by the end of this decade which would be suitable for high volume applications such as sonobuoys.

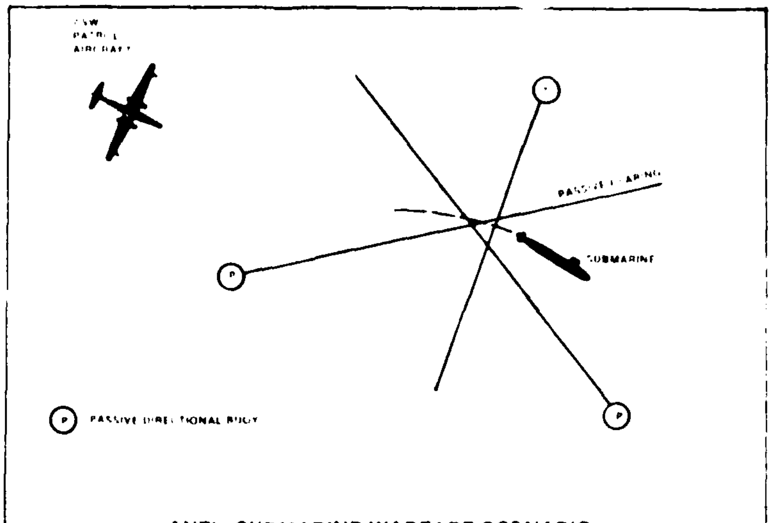
SUMMARY

If this paper has given the impression that Navstar will make all other navigation systems and all smart weapons obsolete, the authors apologize. Although Navstar is the most significant achievement in navigation and position finding in the past several decades, it will not do all things for all users. Although it should render most other radio navigation aids obsolete, it cannot function optimally in many applications without an associated inertial navigation system or inertial measurement unit. However, it will probably be an essential system for most military missions.

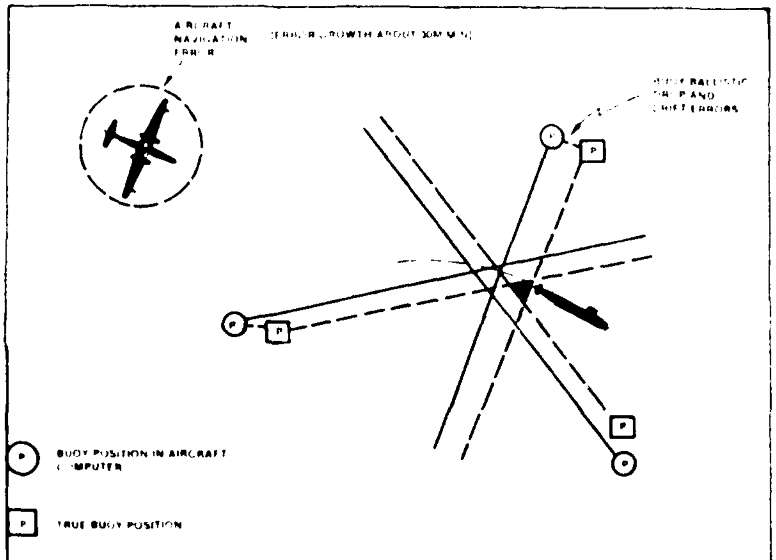
There is an understandable concern among NATO military forces of the potential susceptibility of any radio navigation aid to the impressive EW capabilities of the Warsaw Pact forces. It is also apparent that if one applies enough resources to jamming a particular system, they can achieve partial success. However, GPS has been carefully designed to cope with this type of environment. The use of spread spectrum formats, phased array antennas, and inertial coupling will largely overcome any conceivable level of jamming. Not only can an inertial system provide complementary velocity information as well as extremely accurate heading, it can provide the rate aiding which is essential to enable GPS to maintain operation in the face of heavy jamming. Similarly, many targets will still require smart weapons to defeat them. Navstar should however, reverse the cost trend of these weapons by eliminating the requirement for wide field-of-view sensors and sophisticated navigation systemson each weapon.

By increasing the force effectiveness with much higher first pass successes and by enhancing aircraft survivability through passive operation, Navstar promises to be a force multiplier of great significance in the NATO environment.

The discussion which followed this presentation appears in classified publication CP344 (Supplement)

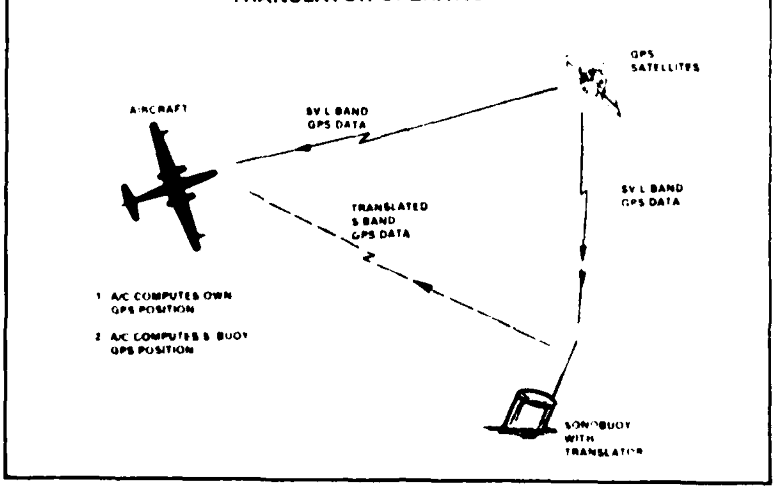


ANTI - SUBMARINE WARFARE SCENARIO



ASW SCENARIO - A/C NAVIGATION AND BUOY GEOMETRY ERRORS

TRANSLATOR OPERATION



COVERAGE AND BUILDUP OF THE NAVSTAR CONSTELLATION

by

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ABSTRACT

Navstar is now in Phase II, the full scale engineering phase. During this phase, a constellation is being maintained with four to five space vehicles to support testing. A buildup of the constellation of 18 space vehicles and three active spares will begin in 1986 and will take approximately 2 years to complete. This paper discusses the coverage with the operational constellation and the factors that determine a strategy for the buildup. It provides information on the navigation capabilities that will be available during the transition from the test to the operational constellation.

The test configuration provides several hours of navigation coverage over selected regions of the earth. As the constellation is built up, availability to users will increase in both duration and in the areas of coverage on earth. About midway through the buildup, complete worldwide, two dimensional navigation coverage will be achieved. Upon completion of the buildup, virtually continuous worldwide, three dimensional navigation coverage will be accomplished.

Because of interest by many users around the world, the sequence in which orbital positions are filled is very important. There are no formal requirements for performance during the buildup, but there is strong interest in achieving the maximum navigation coverage at each step of the way. This paper addresses the performance measures, the constraints, and the objectives used in determining the buildup strategy. The performance achieved during buildup using a candidate strategy is presented.

INTRODUCTION

Navstar is a space based, all weather, continuous navigation system that provides extremely accurate position, velocity, and time information to users anywhere in the world. The program is managed by the Air Force at Space Division as a joint program of all the services, plus the Defense Mapping Agency, the Department of Transportation, NATO, and Australia. The Aerospace Corporation provides general systems engineering and integration.

Navstar is composed of the control segment, the space segment, and the user segment. The control segment consists of the monitor stations, the ground antennas, and the master control station. The space segment consists of the satellites, which broadcast the ranging signals. The user segment consists of the user sets on a variety of host vehicles that receive the satellite ranging signals and perform a navigation solution.

A test constellation is in operation now with four good Block I satellites, a fifth will be launched in June 1983, and three additional Block I satellites are available to maintain the test constellation until operational buildup commences. The test program to evaluate Navstar is being performed primarily at the Army Proving Grounds in Yuma, Arizona, for which the test constellation was designed. However, coverage is available at many other locations (Reference 1). Demonstrations can be, and have been, performed at places other than Yuma.

The operational orbital configuration is a constellation of 18 satellites uniformly spaced in six orbital planes inclined at 55 degrees. In addition, there are three active spares to complete the constellation. The orbits are circular and have nearly 12 hour periods. This configuration will provide continuous three dimensional coverage except for a few regions, which will experience very short periods of degraded performance each day. These regions will have almost continuous coverage.

Transition to the operational configuration will consist of launching the production Block II satellites, so that the combination of the Block I and Block II satellites results in an interim operational constellation with a mixture of orbit inclinations. This will result in slight differences in coverage from the operational configuration. Block I satellites could be replaced before they fail, so that the constellation consists only of Block II satellites which is the operational configuration. The current plan is for Block II satellites to be launched beginning late in 1986 at a rate of eight per year, until the constellation, with spares, is developed.

During the buildup, system performance will have to be superior to satisfy user needs and to maximize worldwide coverage. As requirements become important, they will be factored into the buildup strategy, and the candidate strategy presented in this paper may have to be changed. To meet the requirements, the test configuration will be maintained until it would be beneficial to rephase in order to improve worldwide availability. Since the Space Shuttle has been designated as the launch platform, launch opportunities will be constrained by requirements to share launches with other payloads. This can determine the buildup sequence or at least strongly influence some of the choices. The launch windows of the other Shuttle payloads could restrict the choice of orbital planes for the Navstar satellites. However, analysis has shown that

the launch windows can be opened by making use of Shuttle orbital regression and any reserve capacity of the orbit transfer propulsion system. Therefore, these effects can be reduced, and the unconstrained buildup described in this paper can probably be realized. Also, dedicated Space Shuttle flights are being considered so that the constraints due to sharing would be eliminated. However, delays in reaching some stages of the buildup would occur since it would be necessary to wait until all the satellites scheduled for each launch are ready.

OPERATIONAL CONSTELLATION

The operational constellation is a six plane, uniform 18 satellite configuration plus three active spares. The reason for the active on orbit spares is discussed in a later section. The planes are 60 degrees apart in longitude, and in each plane there are three satellites spaced 120 degrees apart. The phasing from plane to plane is 40 degrees so that a satellite in one plane will have a satellite 40 degrees ahead (North) of it in the adjacent plane to the East. The reference orbit values are given in Table 1. Figure 1 illustrates the constellation orbit planes with the spares. The three spares are required to guarantee a high probability of having 18 or more satellites at all times, with a suitable replacement production and launch rate after establishment of the constellation. In the buildup studies, the spares are added after 18 satellites are in orbit (since they do not contribute as much to coverage as the other satellites).

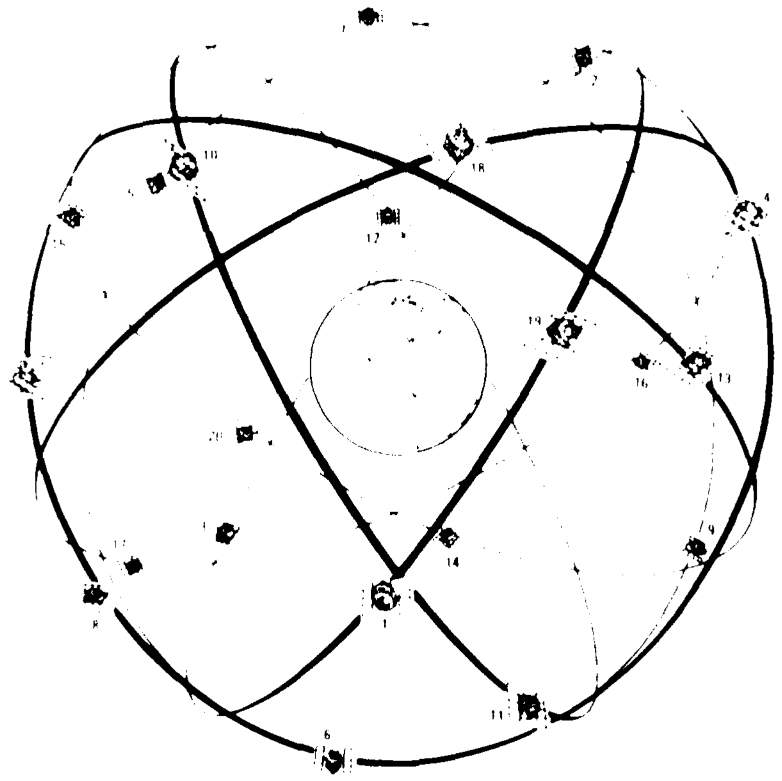
Table 1. Operational Orbit Description Longitude Relative to Earth and Astronomical Coordinates

NUMBER	ORBIT PLANE	LONGITUDE OF THE ASCENDING NODE, deg	RIGHT ASCENSION OF THE ASCENDING NODE, deg*
1	1	0, 180	30
2	1	240, 60	30
3	1	300, 120	30
4	2	260, 80	90
5	2	320, 140	90
6	2	20, 200	90
7	3	340, 160	150
8	3	40, 220	150
9	3	100, 280	150
10	4	60, 240	210
11	4	120, 300	210
12	4	180, 0	210
13	5	140, 320	270
14	5	200, 20	270
15	5	80, 260	270
16	6	220, 40	330
17	6	280, 100	330
18	6	160, 340	330
SPARES			
19	1	195, 15	30
20	5	215, 35	270
21	3	25, 205	150

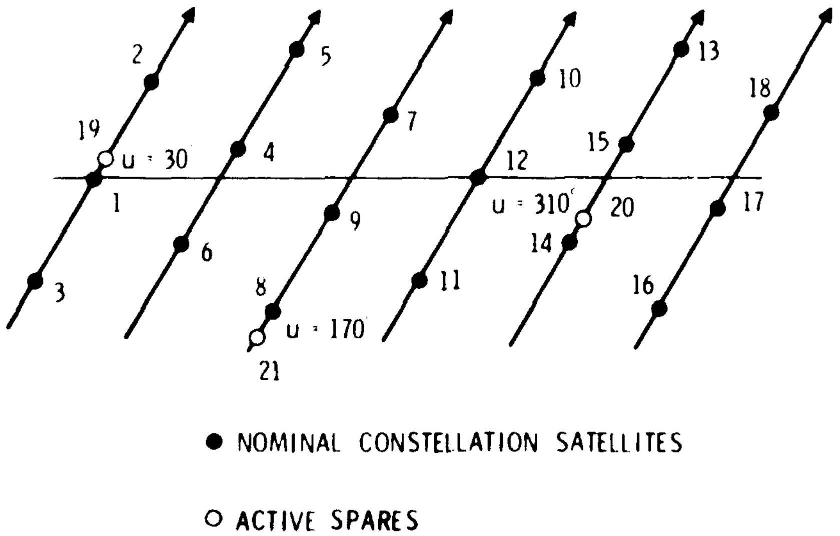
*Referenced to astronomical coordinates of 1950.0 as of 1 July 1985, 0 hr 0 min GMT and regressing at -0.04009 deg/day.

CONSTELLATION VALUE

Position dilution of precision (PDOP) was used as a measure of three dimensional position error. In the case of independent, identically distributed ranging error, the root mean squared three dimensional position error is equal to the rms ranging error multiplied by PDOP (see Reference 2, pp 102 103). For worldwide coverage, constellation value is used as a measure. Constellation value is the fraction of users, worldwide, averaged over time, who have a PDOP less than or equal to six (i.e., PDOP ≤ 6). Availability of the constellation for navigation at specific locations (e.g., Yuma) was also based on PDOP ≤ 6. PDOP ≤ 6 is the threshold used in the system specification (Reference 3). For a specified 7.0 meter ranging error (1 sigma), the threshold of 6.0 for PDOP corresponds to a three dimensional position error of 42 meters rms. The constellation value is computed by sampling points uniformly distributed on the earth over a 24-hour period. On that basis, if the PDOP values for all points are below 6.0, the system value is 1.0. For the six plane, 18 satellite



(a) Illustration



(b) Simplified Representation of Planes

Figure 1. The 6 Plane, 18 Satellite Constellation with 3 Spares

constellation with spares, the constellation value is 0.999. Generally, when PDOP is below 6 it is in the range of 2 to 4. For the operational constellation, the average PDOP is about 2.6.

SPARING AND REPLACEMENT

The on-orbit spares are necessary to maintain an 18 satellite constellation with high probability. A sparing and replacement strategy calling for more than 18 satellites on orbit is required for this to be achieved. Current contractor information indicates that the lifetime of a spare satellite is not appreciably lengthened by maintaining it in a dormant (or semidormant) state. Consequently, spares on orbit have been assumed active for sparing and replacement studies. The studies have indicated that three active on-orbit spares, one in every other plane, are sufficient to guarantee good coverage with high availability.

Availability has been defined as the probability of maintaining a constellation with 18 or more satellites statistically measured as an average over a long period after buildup. The analysis to determine availability is a Monte Carlo technique, and it is based on the space vehicle reliability, the launch reliability, launch delay, and satellite production schedules. The required level of availability is 0.98. The strategy for achieving the required availability consists of either calling for a launch with enough lead time to allow for launch delays when an on-orbit failure is anticipated, or launching on failure, when a ground spare is available.

The analysis demonstrated that a production rate of four satellites per year can maintain the constellation at a 0.98 availability of 18 or more satellites. The average number of operating satellites on orbit is 20 to 21. When there is a spare in a plane that experiences a satellite failure, the spare is rephased to replace the failed satellite. The range of constellation values that may be encountered is illustrated in Figure 2. There it is assumed that if a failure occurs in a plane with a spare, the spare is rephased to replace the failed satellite. Consequently, the worst case failures shown in Figure 2 are not necessarily the worst states that can be encountered. Even when a failure occurs in a non spared plane it is possible to rephase one or more spares and reduce the effect of the failure. However, this strategy was not used in generating Figure 2. The average constellation values are closer to the best values, because of the efficiency of the replacement strategy.

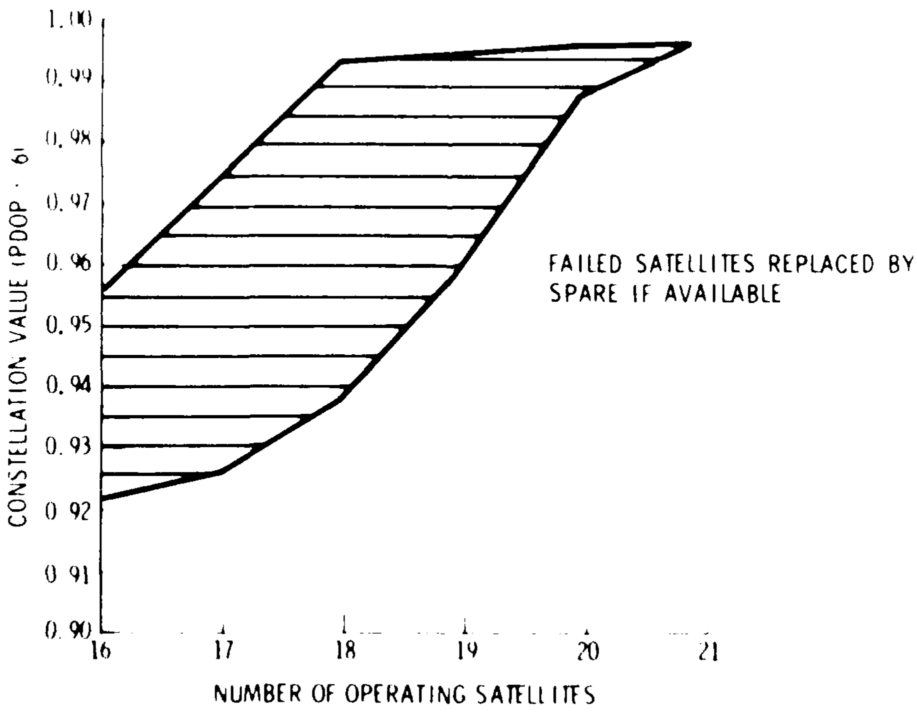


Figure 2. Range of Constellation Values (6 Planes, 18 Satellites Plus 3 Spares)

OPERATIONAL GEOGRAPHICAL COVERAGE

Most users around the world will experience continuous coverage with Navstar. However, at a few locations short periods of degraded performance, called outages, will occur. By plotting the three dimensional outages in coverage regions on a map, their characteristic shapes and relative sizes can be evaluated. In those regions, a user will experience short periods of poor accuracy when relying solely on a Navstar solution to determine position or velocity. The outages are due either to the fact that there are fewer than four satellites in view of the user or to the poor geometry from an adequate number (four or greater) of satellites in view for a solution. Thus, the nature and location of outages are a function of the constellation characteristics. The operational constellation always has four or more satellites in view for a 5 degree mask angles from any point on the earth. Thus, the outages for the operational constellation are due only to poor geometry.

A composite of the outages in coverage for an arbitrary 24 hour period is illustrated in Figure 3 for the operational constellation of 18 satellites plus three spares. The contours are regions in which PDOP exceeds 6. Often these have very large PDOP for a short period of time. Generally, only one outage occurs per day at the indicated locations. For the locations that experience two outages in one day, one generally peaks at some small value (e.g., a PDOP of between 15 and 20) and the other has a large PDOP peak. Furthermore, at any time there are only one to three outages occurring anywhere in the world; no others can occur until 40 minutes or a multiple of 40 minutes later somewhere else in the world. At those times there are no other outages anywhere. Figure 3 shows the total number of outages during a 24 hour period (regions without outages never experience a PDOP greater than 6). Figure 4 illustrates the characteristic PDOP profiles over a 24 hour period at a few specific locations from Figure 3 that experience outages. These show regions with only one outage per day, or two per day with the second being less severe. It is important to note that the duration of time of degraded coverage (i.e., outage) is very short. Because the time duration of the outages is so short, it is possible to compensate for these periods with aids as simple as an altimeter and, thus, essentially eliminate the effect of the outage. Situations with long duration outages, as encountered in the early and middle stages of buildup to the operational constellation, cannot be totally compensated.

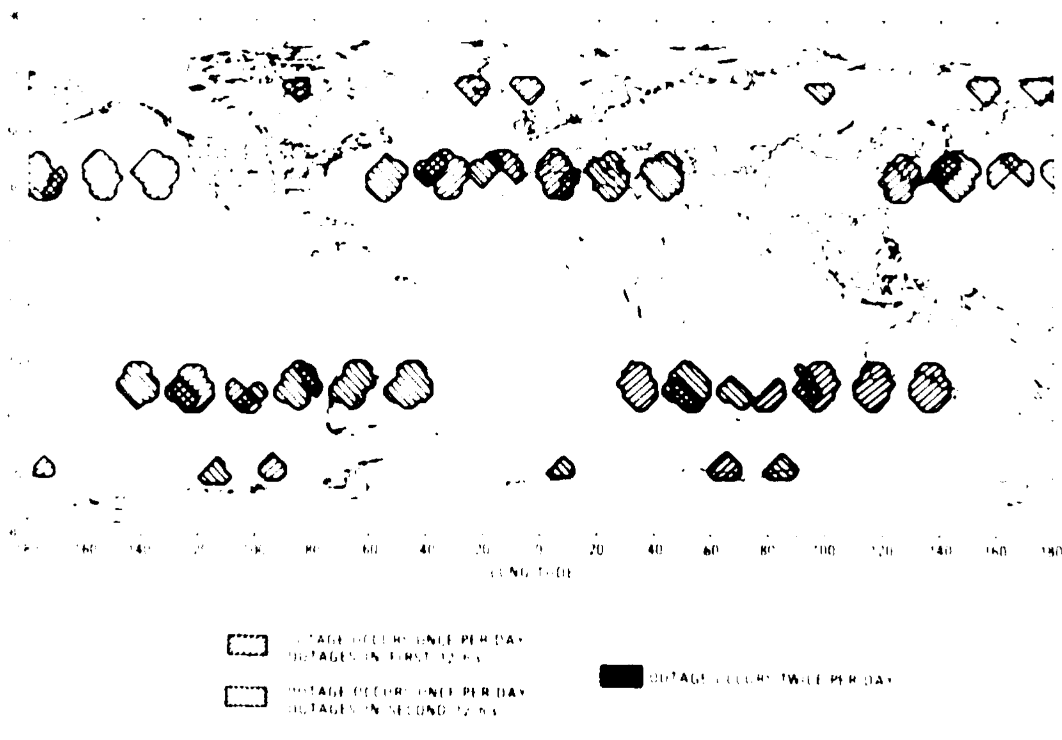


Figure 3. Daily Composite Operational Coverage (PDOP 6)

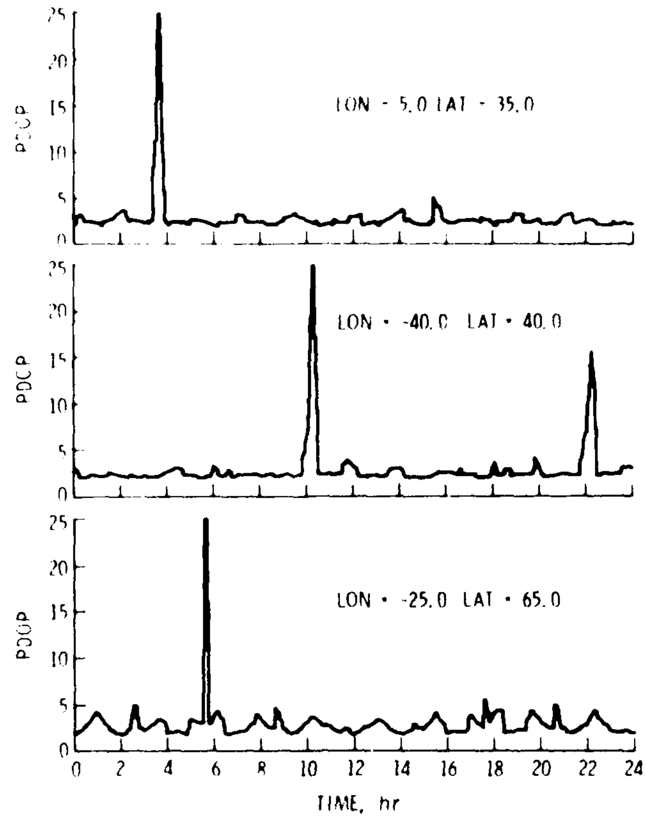


Figure 4. Sample PDOP Profile at Locations That Experience Outages for the Operational Constellation

TEST CONSTELLATION

The concept validation phase (Phase I) of the program (1974-79) carried a three plane, 24 satellite constellation as the planned operational constellation. There were eight satellites per plane; the planes were 120 degrees apart in longitude inclined at 55 degrees; and the satellites were uniformly spaced at 45 degrees apart in each plane, with a plane to plane phasing of 30 degrees.

The Phase I constellation of from four to six satellites was designed to replicate to the greatest degree possible a portion of the then future 24-satellite configuration. The constraints imposed by the Atlas launch vehicle required that the Block I test satellites be placed in orbits with an inclination angle of 63 degrees, whereas the operational Block II satellites that will be launched from the Shuttle will be placed in orbits inclined at 55 degrees. Following Phase I, the operational constellation was reduced to an 18-satellite configuration because of program restructuring. This at first lead to selection of a three-plane, non uniform constellation (Reference 4) and eventually to the six-plane, uniform 18-satellite constellation (Reference 5), but the test constellation was not altered from the original concept.

The current constellation consists of four good satellites, Navstars 3, 4, 5, and 6. Navstar 8 is scheduled to be launched in June 1983. It will replace Navstar 1, which is not being used for navigation because it is operating only with a quartz crystal clock and is not providing good accuracy. The orbital parameters existing after the launch of Navstar 8 are shown in Table 2. The test configuration position numbers, which do not correspond to the Navstar numbers (nor to the position numbers of the operational configuration in Figure 1), are shown. Position 4 will remain vacant because retention of only five satellites for testing is planned. After the launch of Navstar 8, there will be three more Block I satellites (Navstars 9, 10, and 11) available as spares to maintain the five-satellite constellation. It is currently projected that Navstar 9 should be launched in October 1983 and the last two satellites launched in mid 1984 and mid-1985 to maintain the test configuration. The five satellite constellation is the

starting point for the buildup to the interim operational constellation starting in 1986. However, based on reliability analysis, it is presently anticipated that there may be as few as four satellites or as many as six when the operational buildup begins. The study assumes that the five Block I satellites will continue to operate until buildup is completed, resulting in the mixed orbital inclinations of the interim operational constellation.

Table 2. Navstar Orbital Parameters for Test Phase Constellation at First Ascending Node Referred to 1 July 1980

Navstar Number	Position Number	Orbital Parameters: Right Ascension of Node, deg.	Longitude of Node, deg. E	Time of Node, GMT	Inclination, deg
3	6	80.61	353.0 ±2	$11^h15^m21^s$ ±8^m	63.29
4	3	201.17	269.5 ±2	$0^h51^m18^s$ ±8^m	63.14
5	1	201.03	227.0 ±2	$3^h40^m16^s$ ±8^m	63.64
6	5	81.05	152.0 ±2	$0^h40^m51^s$ ±8^m	63.09
8	2*	202.26 ±2	248.5 ±2	$2^h19^m25^s$ ±16^m	63.00 ±1
-	4**	82.26 ±2	130.5 ±2	$2^h11^m26^s$ ±16^m	63.00 ±1

* Location where Navstar 8 is to be placed when launched; only first four positions are currently used.

** Empty slot.

BUILDUP REQUIREMENTS AND CONSTRAINTS

The initial buildup was selected to build on the test configuration for the Yuma Proving Grounds, the best worldwide coverage can be obtained by maintaining the cluster of satellites for testing, since early rephasing would cause undue separation between the satellites. This would lead to low visibility; that is, there would be less chance of seeing three or four satellites simultaneously, which is the necessary condition for two dimensional and three dimensional solutions, respectively. Low visibility would result in reduced Yuma coverage and poor worldwide coverage. Consequently, rephasing of the test cluster must be delayed until enough satellites are in orbit so that when the cluster is broken up both the worldwide coverage and the Yuma coverage are still good.

Figure 5 shows the test configuration and the operational configuration relative to each other. The positions are shown at the instant that position number 1 of the operational constellation crosses the equatorial plane. All other positions are shown relative to that origin. Also illustrated is the proposed rephasing of the test satellites.

CANDIDATE BUILDUP SEQUENCE

Maximizing Yuma and worldwide coverage are compatible goals during the early phase of the buildup, but when 10 or 11 satellites are in orbit the two criteria are at odds. To determine the best sequence of satellite additions, the coverage time at Yuma and the worldwide coverage were determined for each candidate addition to the constellation. This was done starting with the addition of the sixth satellite and continuing through 12 satellites in orbit. When there were eight or more satellites in orbit, the performance of the constellation was evaluated for both the existing arrangement of the test configuration satellites and the arrangement that would result if these satellites were rephased to place them in the interim operational constellation positions. Eleven different buildup sequences were considered in the final screening. Each of these was obtained by carefully considering the applicable criteria for each satellite addition and in determining the proper point to rephase. The rephased and non rephased worldwide constellation values for the selected buildup sequence are shown in Table 3. The navigation coverage at Yuma for rephased and non rephased arrangements is shown in Table 4; available time shown considers only intervals of continuous coverage of one or more hours. For the selected buildup sequence, the rephasing should be done after the tenth satellite is added. The constellation value is better for the rephased constellation for 10 or more satellites,

and the Yuma availability drops only slightly with the rephasing (see Tables 3 and 4). The remainder of the buildup is driven by the worldwide availability. The buildup is continued to 18 satellites; then the spares are added to complete the constellation.

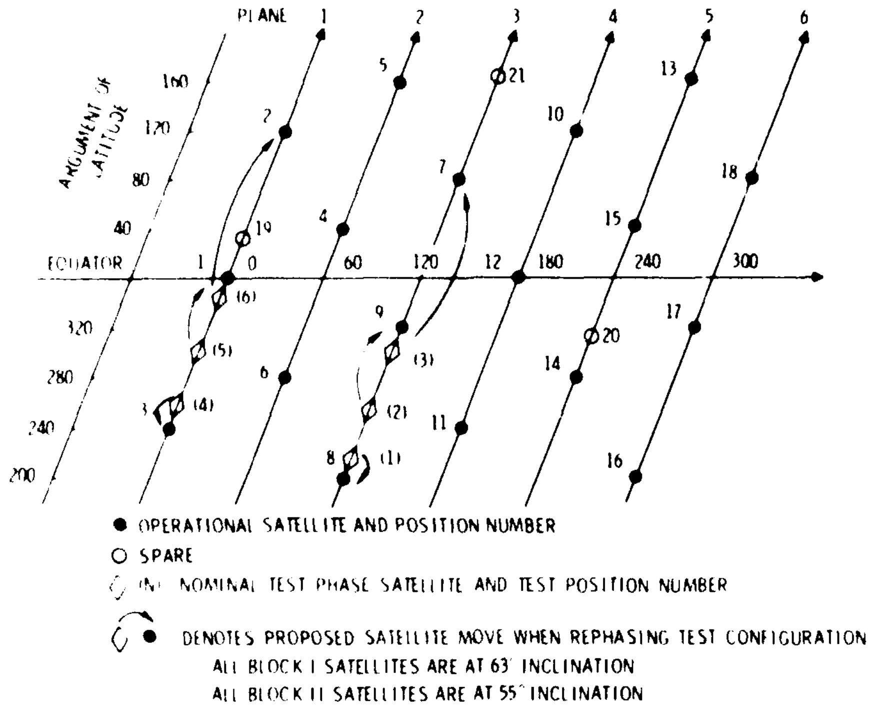


Figure 5. Operational Configuration with Test Phase Locations Superimposed

Table 3. Buildup in Worldwide Constellation Value

NUMBER OF SATELLITES	POSITION NUMBER OF ADDED SATELLITES	CONSTELLATION VALUE	
		NON-REPHASED	REPHASED
5	-	0.077	
6	(4)	0.148	
7	18	0.198	
8	13	0.257	(0.163)
9	10	0.324	(0.275)
10	15	(0.387)	0.391
11	17	(0.437)	0.494
12	16		0.594
13	14		0.740
14	11		0.839
15	12		0.923
16	5		0.950
17	4		0.974
18	6		0.995
19	19*		0.996
20	20*		0.998
21	21*		0.999

* Spares

Constellation is rephased at 10 satellites; these cases would not be used.

(4) Test position, but at 55-deg inclination. (May be at 63 deg depending on initial test configuration; results in slight change in constellation value but no change in buildup sequence.)

Table 4. The Buildup in Navigation Coverage at Yuma, Arizona

Number of Satellites	Position Number of Added Satellite	Yuma Availability* Non rephased (hr/day)	Yuma Availability* Rephased (hr/day)
5		2.3	
6	(4)	4.5	
7	18	4.5	
8	13	6.6	
9	10	7.7	(4.8)**
10	15	(9.0)**	8.8
11	17	(9.0)**	9.8
12	16		10.8
13	14		13.9
14	11		19.0
15	12		22.3
16	5		22.3
17	4		22.5
18	6		23.2
19	19+		23.6
20	20+		23.6
21	21+		24.0

\+ Spares
* For intervals of 1 hour or more.
** Constellation is rephased at 10 satellites; these cases would not be used.
(4) Test position, but at 55-deg inclination.

The buildup time of coverage at Yuma is paralleled at other locations around the world. Table 5 shows daily navigation coverage in hours of coverage at 42 cities for 6, 8, 10, 12, 15, and 18 satellites, and 18 satellites plus three spares. Only blocks of coverage that have PDOP less than or equal to 6 continuously for one hour or more are counted.

Although the actual buildup sequence will probably differ somewhat from that shown here, the fact that there were a number of comparable buildup sequences indicates that, unless the constraints are really stringent, comparable performance should be achievable. The main factor that seems to differ is the quality of the coverage: i.e., are large blocks of continuous coverage available or are there many smaller blocks of time? Generally, one would prefer large blocks of time. The selected sequence exhibits this property and generally had longer duration blocks of continuous coverage over 24 hours at more places of interest. Some competing buildups had almost as long a total period of coverage over a 24-hour period. However, the coverage included many small blocks of time at intermediate stages of the buildup.

CONCLUSION

Except for very brief periods of degraded performance, occurring once or twice per day at a few locations in the world, excellent continuous navigation performance is available worldwide with the operational Navstar configuration. In those regions where some degradation can occur some form of aiding can circumvent the outage.

This paper describes a candidate buildup sequence for establishing the constellation. The coverage availability, both at the Yuma Proving Grounds and worldwide, was the primary criterion for selecting the order. It was shown that large blocks of time are available at all locations using the selected sequence. Other candidates exist but were not as good; some of the sequences came close to the selected candidate, but the coverage was of lesser quality. There were shorter periods of total coverage over a 24-hour period at points of interest, or the coverage was made up of smaller blocks of time, or both.

Analysis will continue toward the selection of a preferred sequence for buildup. New user requirements will be included, and shuttle constraints are being examined. Final selection of a buildup sequence will also depend on the actual state of the constellation during the buildup. In any case, the launch schedule indicates that two-dimensional coverage should be available by the latter part of 1987, when 12 or 13 satellites are on orbit. Full three-dimensional coverage, barring failures, should be available by the latter part of 1988.

Table 5. The Buildup in Navigation Availability at 42 Cities

USER LOCATION	NUMBER OF SATELLITES						
	6	8	10 ·	12 ·	15 ·	18 ·	18 PLUS 3 SPARES ·
	HOURS OF COVERAGE*						
ACAPULCO, MEXICO	3.1	6.3	8.9	12.6	22.2	24.0	24.0
ANCHORAGE, ALASKA	2.8	3.9	6.4	11.8	19.5	24.0	24.0
ANKARA, TURKEY	4.0	4.9	7.9	10.7	21.0	23.5	24.0
BRUSSELS, BELGIUM	2.1	2.1	5.3	13.4	22.0	24.0	24.0
BUENOS AIRES, ARGENTINA	3.8	[illegible]	6.7	9.7	19.4	23.5	23.6
CAMP PARKS, CALIFORNIA	4.5	[illegible]	7.9	10.6	21.6	23.6	24.0
CALCUTTA, INDIA	4.9	5.8	6.6	13.0	23.8	24.0	24.0
CAPE KENNEDY, FLORIDA	4.6	[illegible]	6.0	12.4	22.3	24.0	24.0
CAPE TOWN, SOUTH AFRICA	3.9	4.3	6.6	10.8	20.2	23.1	24.0
CARACAS, VENEZUELA	3.5	5.8	9.9	14.0	24.0	24.0	24.0
CHARLESTON, SOUTH CAROLINA	4.5	5.8	6.6	11.3	21.0	23.9	24.0
CHRISTCHURCH, NEW ZEALAND	5.0	5.0	6.4	10.4	19.0	24.0	24.0
COLD LAKE, CANADA	4.9	5.3	9.2	12.5	22.5	24.0	24.0
DIEGO GARCIA	N/A	6.3	8.0	10.0	20.9	24.0	24.0
EGLIN AFB, FLORIDA	4.8	5.9	5.4	12.1	21.2	24.0	24.0
FARNBOROUGH, UNITED KINGDOM	2.0	3.1	5.2	13.7	22.6	24.0	24.0
FORT MONMOUTH, NEW JERSEY	3.9	4.0	8.6	11.2	19.2	23.3	24.0
FORTUNA, NORTH DAKOTA	5.0	5.1	7.4	11.5	21.6	24.0	24.0
GALVESTON, TEXAS	5.0	5.5	6.4	11.2	22.1	24.0	24.0
GRAND BAHAMA ISLAND	4.1	5.9	6.0	12.0	22.3	24.0	24.0
GUAM	N/A	4.2	3.8	5.0	21.9	24.0	24.0
HONOLULU, HAWAII	3.4	6.6	7.6	14.9	22.8	24.0	24.0
HORMUZ	4.5	6.9	7.2	9.7	20.7	24.0	24.0
LAS PALMAS, CANARY ISLANDS	N/A	3.5	4.8	11.6	21.9	23.6	24.0
LIMA, PERU	3.4	7.8	9.2	16.5	23.5	24.0	24.0
NEW HAMPSHIRE (SCF)	3.3	3.3	7.9	11.[illegible]	18.6	23.7	24.0
NEW LONDON, CONNECTICUT	3.6	3.6	7.6	10.8	18.[illegible]	23.3	24.0
PAGO PAGO, AMERICAN SAMOA	3.0	5.7	8.4	15.8	22.6	24.0	24.0
PANAMA CANAL	1.7	7.1	8.3	14.9	22.0	24.0	24.0
RIYADH, SAUDI ARABIA	4.7	7.0	7.2	8.8	21.9	24.0	24.0
ROME, ITALY	2.8	3.3	8.5	12.5	21.0	24.0	24.0
SEYCHELLES ISLAND	1.0	4.8	8.8	10.2	22.1	24.0	24.0
SYDNEY, AUSTRALIA	4.4	6.8	8.4	9.5	21.6	23.5	24.0
STOCKHOLM, SWEDEN	2.5	4.7	7.1	14.7	21.9	23.9	23.9
TAIPEI, FORMOSA	2.8	3.7	5.8	9.4	22.2	24.0	24.0
TANANARIVE, MALAGASY REPUBLIC	N/A	3.4	5.8	6.8	22.0	24.0	24.0
TEL AVIV, ISRAEL	4.0	5.8	6.5	8.7	19.5	23.8	23.8
THULE, GREENLAND	3.7	4.2	7.3	15.3	22.2	24	24.0
TOKYO, JAPAN	1.2	3.6	4.6	6.3	20.4	23.2	23.2
TROMSO, NORWAY	2.9	2.9	5.7	11.9	21.8	23.9	24.0
VANDENBERG AFB, CALIFORNIA	4.4	6.7	8.7	10.8	22.1	23.7	24.0
YUMA, ARIZONA	4.5	6.6	8.8	10.8	22.3	23.2	24.0

* For continuous coverage intervals of 1 hour or more for PDOP < 6 (coverage lasting less than 1 hour is not counted)

· Constellation rephased when a tenth satellite is added (mixed inclinations)

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The discussion which followed this presentation appears in classified publication CP344 (Supplement)

TACTICAL APPLICATIONS OF GPS USER EQUIPMENT

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ABSTRACT

The briefing covers GPS user equipment with emphasis on system strengths and weaknesses which affect tactical applications of GPS. A short description of GPS operation is followed by a discussion of signal outages, selective availability, jamming scenarios and vulnerabilities. Presented next are discussions on previous test results, expected future testing and demonstrated capabilities such as passive rendezvous, precision runway approach and blind bombing.

Integration and aircraft installation programs are also addressed along with rationale for TAF GPS aircraft priorities, concepts of operations for search and rescue, special operations, reconnaissance and master navigation plan impacts.

The discussion which followed this presentation appears in classified publication CP344 (Supplement)

DEFENSE METEOROLOGICAL SATELLITE PROGRAM (DMSP)

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ABSTRACT

The DMSP is a total satellite system composed of spacecraft with meteorological sensors, an earth based command and control network, fixed and mobile user stations, and a communication network linking the various segments together

INTRODUCTION

The mission of DMSP is to provide global meteorological data to Tri-Service Commanders in support of worldwide military operations, both strategic and tactical, and to advance spaceborne meteorological sensing technology to meet changing Department of Defense requirements. The Space Segment consists of satellites in 830 kilometer sun synchronous polar orbits each carrying a payload of various meteorological sensors. The Satellite Operations Center is located at Offutt AFB, Nebraska, with earth terminals located at Loring AFB, Maine, Fairchild AFB, Washington, and the AF Remote Tracking Station, Hawaii. Real-time cloud imagery data is transmitted directly from the spacecraft to Air Force, Navy, and Marine Corps ground tactical terminals and Navy carriers located throughout the world. Stored or playback meteorological data is transmitted to centralized processing facilities at the Air Force Global Weather Central (AFGWC) at Offutt AFB, Nebraska, and the Navy's Fleet Numerical Oceanography Center (FNOC) in Monterey, California. At these centralized facilities, global cloud cover and other meteorological sensor data can be merged with more conventional data and distributed to provide weather support throughout the Department of Defense. In support of the command and control, telemetry and meteorological data, the system uses domestic communication satellites and land lines to interconnect the various segments in a cohesive and responsive manner.

SPACE SEGMENT

The spacecraft consists of a three-axis stabilized vehicle with an on-orbit weight of 725 kilograms and 3.5 meters in length exclusive of solar panels. It has a pointing accuracy of 0.01° and a 30-month mean mission duration.

Sensor

The Operational Linescan System (OLS) is the primary meteorological sensor. The OLS is a complete self contained data collection system consisting of an oscillating scanning radiometer and a data processing and storage subsystem which provide meteorological imagery data (cloud cover) on a global basis. The system collects day and night earth scene image data which is then transmitted in real time and/or stored over multi orbits.

Earth scene data is sensed by the OLS in two complementary spectral bands: visible light and thermal infrared. In each channel the scene resolution across scan is made nearly constant by using a variable instantaneous field of view in conjunction with a sinusoidally varying scan motion. For global coverage the nominal "smoothed mode" resolution is 2.78 km in each channel and for selected regional coverage with higher resolution a nominal 0.56 km "fine mode" is provided in each channel.

The visible channel senses scene radiance in the 0.4 to 1.1 micrometer spectral band for scene illuminations ranging from sub-solar to sub-lunar at quarter moon, a range of over ten million to one. The infrared channel senses scene radiance in the 10 to 13 micrometer spectral band corresponding to a scene temperature range from 190°K to 310°K. The output data is made linear with temperature over the dynamic range.

The visible channel detectors are three-segment silicon photoconductive PIN diodes for daytime scenes and a cesiated gallium arsenide opaque photocathode for nighttime scenes. The infrared detector is a two-segment Mercury-Cadmium-Telluride photoconductive detector cooled to a temperature near 108°K and maintained within $\pm 0.1^{\circ}$K of the chosen set point. The imagery data across the scan path is collected in the form of discrete picture elements (pixels) and converted into one of either 64 or 256 grey shades.

The program and data storage are provided by the OLS memory consisting of 3K of ROM and 13K of CMOS RAM. In addition, there is 16K of core RAM memory. Processed meteorological data is stored on four magnetic tape recorders, each having a storage capacity of 1.67×10^{9} bits.

In addition to the OLS, the spacecraft has other meteorological sensors, some of which may employ advanced spaceborne meteorological sensing technology. These include atmospheric sensors such as a multispectral infrared radiometer or a microwave temperature sounder and various space environmental sensors such as electron and ion temperature and density sensors, an X-ray detector, and a precipitating electron spectrometer.

Communications and Telemetry

For meteorological data transmission the spacecraft communications subsystem incorporates three independent S band links using PCM/PSK transmission at 1.024 Mbps real time and 2.66Mbps playback data rates. The transmitters are 5 watt solid state units used in conjunction with crossed dipole directive antennas mounted on the earth facing side of the spacecraft. In addition, there are redundant S band telemetry links for spacecraft status, one using a high gain directive antenna while the other is omnidirectional with two half turn, half wave helical antennas. This telemetry link uses PCM/PSK/PM modulation.

The uplink command system operates at a 2K rate and has tertiary MFSK/AM modulation. The receive L band antennas are similar to the telemetry omnidirectional units.

The telemetry unit is a solid state CMOS system under microprocessor control using 4K of PROM and 2K of RAM. With three commandable data rates of 2, 10 or 60 kbps, it also has numerous commandable submodes, i.e., ability to obtain OLS, spacecraft and telemetry memory dumps, to sample analog channels using higher sampling rates, and to rearrange analog and discrete channel assignments.

Command and Control

The command and control subsystem is the focal point for all spacecraft functions and operations. It includes a Control Interface Unit which is an input/output device through which all data and instructions flow. The subsystem also includes computers and memories which control all spacecraft functions, a stable spacecraft clock, and processing to decode and distribute all commands. Two central processing units are used, each having 28K read/write memories. The subsystem multiplexes its own internal telemetry data stream, composed of attitude and control parameters for insertion into the telemetry data format.

The software elements of the command and control subsystem process command messages and data loads, maintain the status of the hardware, and generate control signals to all elements of the spacecraft, both hardware and software. The Ascent Guidance Software provides the navigation, upper stage thruster control, velocity trim and final orientation maneuvers during ascent through orbital insertion. The Orbit Mode Software provides attitude determination and control after achieving orbit.

Attitude Determination and Control

The accurate (0.01 degree) three axis attitude determination and control subsystem provides precise pointing of the sensor payload. Three on board orthogonal gyroscopes measure short term changes in attitude; a star sensor measures long term drift. An on board processor stores ephemeris data and computes the spacecraft attitude. To enhance pointing accuracy, extensive star catalogs and ephemeris tables are periodically transmitted to the spacecraft from the ground. Attitude control is provided by three reaction wheels in an active closed loop configuration (with a fourth for back up), magnetic coils for unloading excess momentum, and GN_2 thrusters for transient momentum disturbances. In the event of failure of the Inertial Measurement Unit or Celestial Sensor Assembly, a lower accuracy (0.1 degree) three axis attitude determination and control is available. It is provided by the Earth Sensor Assembly and the Sun Sensor Assembly.

Other Spacecraft Subsystems

The other subsystems consist of a power system which includes photovoltaic solar cells, two nickel cadmium secondary batteries and power conditioning electronics, a single axis control system to allow the solar array to track the sun, and both passive and active thermal control systems.

GROUND COMMAND AND CONTROL SEGMENT

The DMSP spacecraft has an extensive worldwide system available to provide support for meeting the mission objectives. In addition to the three earth terminals and domestic communication satellite network mentioned earlier, it has the added resources of the Air Force Satellite Control Facility's worldwide Remote Tracking Stations and the extensive DOD communication satellite network to provide telemetry and command backup. All of these resources are presently linked via terrestrial or satellite links.

Satellite Operations Center

The Satellite Operations Center (SOC) at Omaha is the primary command and control site and contains the personnel and systems necessary to conduct all mission planning, spacecraft commanding, telemetry ingest and post pass analysis.

Mission planning encompasses all tasks associated with data generation and scheduling for the ground system and satellite operating activities. It synthesizes the user's data needs, engineering requests for special satellite tests, and processes satellite status information to create the operational data files necessary to control the DMSP satellite system. These requirements and operational constraints are then incorporated into the automated Mission Planning Data Generation and Verification System (PLANS).

The Stored Telemetry Processing System (STPS) provides data analysts with the means to conduct post pass, long term telemetry analysis of spacecraft anomalies. The system operates either interactively or in the batch mode. For real time telemetry, the SOC utilizes specially built decommutators to separate out spacecraft telemetry data for computer processing. Real time processing provides conversion to engineering units and identification of out-of-limit parameters, all displayed on color graphic terminals. Once the satellite contact period is over, the stored telemetry and the real time telemetry are merged into the revolution by revolution telemetry data base, and are then accessible for post pass computer analyses.

Satellite Communications

At each of the three earth terminals, the meteorological and telemetry data are multiplexed together with site status data and a digital voice channel into a single 3.072 Mbps data stream. The 3.072 Mbps data stream from the Hawaii tracking Station does not contain digital voice. The channels from the three sites are uplinked to the Westar satellite, leased from Western Union by the American Satellite Corporation, and relayed to terminals located at AFGWC, Nebraska, and FNOC at California. Both sites receive all the data contained on all three channels. The command channel from the Omaha Satellite Operations Center to the two Command Readout Stations (CRS's) is a single time division multiplexed (TDM) channel that contains a composite of command, control and digital voice at 230.4 kbps. The command data stream is converted from a serial to ternary form at each CRS and uplinked to the spacecraft.

The primary links to the CRS's are backed up by terrestrial land lines that are capable of handling the same types of command and telemetry data as Westar but at a lower data rate. The terrestrial lines do not provide mission data to AFGWC. In addition, there are command/telemetry back up links to/from the Air Force Satellite Control Facility, the spacecraft factory and Vandenberg AFB for launch and test support.

Command Readout Stations

The Command Readout Stations, located at Loring AFB, Maine and Fairchild AFB, Washington, consist of earth terminals for accessing and receiving data from the spacecraft. The antenna system has a 12 meter reflector with a G/T of 20.75 dB/^{o}K and uses pseudo monopulse autotracking.

In addition to processing and transmitting commands in real time, the terminals have a local commanding capability by means of command data shipped in advance from the SOC PLANS computer. The extent of this stand alone operation is dependent upon the quantity of command data resident at the local site.

The downlink function receives, stores and forwards all incoming S band signals to the two centralized user segments.

USER SEGMENTS

Global Weather Central

The Air Force Global Weather Central (AFGWC) is the largest military meteorological center in the world and provides worldwide meteorological and space environmental support to not only the Air Force but to the Army and a variety of Defense Department agencies as well. In addition, AFGWC backs up the National Weather Service's National Meteorological Center and the National Severe Storms Forecast Center.

Meteorologists at AFGWC use a combination of conventional data (rawinsonde, radar, aircraft, and ship observations) and satellite data (DMSP, GOES, and NOAA) for both their meteorological and space environmental customers. Conventional data is transmitted into GWC over the Automated Weather Network (AWN) from military bases within the CONUS and from overseas. Global Weather Central also acquires additional weather data from civilian sources such as the FAA, the National Meteorological Center, and commercial airlines.

All these data sources feed into GWC which, operating under a build and apply philosophy, devotes much of its resources to building a variety of data bases. The remaining resources go toward meteorological applications of these various data bases. Among the many thousands of products created and transmitted from GWC daily are MAC computer flight plans, other computer flight plans, terminal forecasts, facsimile charts, some 100 to 150 point weather warnings, and as many as 150 requests for special forecast assistance.

DMSP satellite data is used in a variety of ways at GWC to support both meteorological and space environment customers. Global cloud imagery, visual and infrared, is made available to the forecaster in several different ways. He may receive a positive transparency for use on a light table or a hardcopy print on which he can conduct an analysis. The imagery is also processed directly into the Satellite Global Data Base (SGDB). With each new batch of stored data into GWC, this data base is updated. The meteorologists then use the SGDB to reconstruct computer generated images of any area of the globe or merge this data with conventional data to produce the world's only three-dimensional cloud analysis model. With additional input from numerical forecast models, a short-term cloud forecast can be generated.

The tropical meteorologist at AFWC has found DMSP cloud imagery to be particularly useful. In areas of the world where there are virtually no conventional observations, typhoon location and tracking have been traditionally accomplished by aircraft reconnaissance. However, as this resource has decreased, DMSP has become increasingly more important to both naval and fixed base forces.

DMSP data has also been found very useful in the construction of hemispheric weather depiction charts. These charts show areas of cloudiness, cloud type, icing, and turbulence. Wind direction vectors can also be extracted from DMSP pictures and used for upper-air analyses performed at GWC. The severe weather forecaster also uses cloud imagery to locate areas of potential instability and to assist in the preparation of point weather warnings.

In addition to cloud imagery, the forecaster has additional DMSP data available from a variety of infrared and microwave sounders and imagers. Among the types of information these sensors provide are vertical temperature profiles. By sensing infrared and microwave radiation transmitted by the earth and by atmospheric gases, (CO_2, O_2), the meteorologist can reconstruct temperature profiles. This type of information has long been used as the basis for atmospheric analysis and forecasting. Prior to the advent of satellite remote sensing, temperature profiles were obtained solely from instrumented balloons, with severely limited coverage. With DMSP we now have worldwide coverage which fills in the data void regions. By improving our initial analyses we also improve our numerical forecasts. These forecasts predict large-scale weather systems that ultimately affect the local weather. They also predict the winds that are required for computer flight plans, wind trajectory models, and other wind and density forecasts.

Navy Fleet Numerical Oceanography Center

The Navy Fleet Numerical Oceanography Center (FNOC), Monterey, California, receives the identical mission data as Global Weather Central via AMSAI relay. The weather data can then be transmitted via terrestrial links to secondary facilities at Pearl Harbor, Guam, Norfolk and Spain for detailed processing for local weather reports. The DMSP satellite data is also used in a variety of ways at FNOC, both alone and merged with more conventional data to provide meteorological support to Navy ships and facilities worldwide.

Mobile Terminals

The Mark IV is the latest generation, mobile, receive only, ground terminal to provide real time DMSP visual and infrared cloud imagery data to theater decision makers. It is a compact unit consisting of a 3 meter parabolic antenna, 6 meter van, and an auxiliary power generator, designed to be transported aboard C 130 or C 141 aircraft. It has automated acquisition and tracking and a low noise front end with a G/T of 11.3 db/^{o}K. The Mark IV has the capability to track and process data from both the DMSP and NOAA weather satellites. Hard copy data can then be provided to at least four remote locations over cable and telephone circuits. Mark IV's are intended to be co located with theater commanders and are planned for deployment to Europe, Alaska, Pacific, Far East, Central America, United Kingdom, and CONUS.

The 1.024 Mbps serial, real time data is demodulated and formatted for processing while being simultaneously recorded along with time code information on an analog tape recorder. The formatting consists of a serial data synchronization process, a serial to parallel data conversion, and a decommutation process. The decommutation process extracts the visual or infrared imagery data and the other auxiliary data. The imagery data is the primary data input for display generation, with the auxiliary data being used for appropriate image correction. The visual or infrared images can be enlarged, enhanced, labeled and gridded within 30 seconds of a satellite pass.

In the real time mode, the imagery data is formatted, corrected for earth curvature and wow/flutter effects, enhanced and overlayed, and sent to hard and soft copy displays. The hard copy is a laser scanned, dry processed film transparency suitable for light table viewing and photographic reproduction, while the soft copy is a CRT monitor display.

The capability to search through the entire pass at normal magnification using the soft copy display is accomplished by commands entered via the operator's console keyboard. The normal magnification scene is 3000 km square at a 1:15 million scale. For times two and four magnification, the displayed scene will be 1500 and 750 km square respectively. From each spacecraft pass, an area up to 8000 km long and 2000 km wide can be covered. By 1988, there will be up to 27 of these terminals operational worldwide.

Shipboard Terminals

The Navy has shipboard receiving terminals on the John F. Kennedy, Enterprise, Independence, Midway, and Kitty Hawk. In the future, they will be installed on nine additional ships, such as the Nimitz, Coral Sea, Constellation, etc. Their operation is very similar to that of the previously discussed mobile terminals.

FUTURE PLANS

The future of DMSP does not foresee immediate, dramatic technological changes but, rather, a deliberate enhancement of the various subsystems, technology permitting. Primarily, these include increasing system lifetime by obtaining parts with improved reliability, that are less susceptible to radiation effects and have increased yields. Error detection and correction will also be incorporated into future spacecraft computer systems.

Future efforts will include the study of satellite autonomous operation, up to six months with little or no support from the ground operations centers. This could involve significant changes to the overall spacecraft, including power and redundancy management, data handling and software systems to achieve the stated goals.

Other future considerations include moving out of the crowded S band RF frequency to the higher EHF band. While not technology limited, such a change would have severe impact on the numerous fixed and mobile ground terminals and poses a challenge to be able to transition with minimum operational effect.

As in the past, advanced state of the art special sensors will continue to be flown to provide additional meteorological information and further the sensing technology.

The discussion which followed this presentation appears in classified publication CP344 (Supplement)

MILITARY APPLICATIONS OF METEOROLOGICAL SATELLITE (METSAT) DATA

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SUMMARY

This paper addresses the military applications of METSAT data and, in particular, Air Weather Service's (AWS) processing and use of data from the US Department of Defense METSAT, the polar-orbiting Defense Meteorological Satellite Program (DMSP). The primary mission of AWS is to support US Air Force and US Army operations. In modern warfare, the presence or absence of clouds directly impacts the ability to successfully and economically perform the military missions, and with the recent development of extremely expensive cloud-sensitive weapon systems, the accuracy of cloud information assumes an even greater role. AWS processes and uses all available data to satisfy mission requirements. Peacetime cloud data sources include the DMSP, NOAA polar orbiting and geostationary satellites, worldwide surface and upper air weather data, and foreign geostationary METSATs. In wartime, the Defense Meteorological Satellite Program may be the only consistent source of meteorological data. DMSP provides data to AWS in two modes--direct readout and recorded. Direct readout data are received through transportable terminals on land and sea and provide direct cloud imagery support to Army and Air Force field commanders and Navy operations afloat. Recorded DMSP data received at the Air Force Global Weather Central (AFGWC) and the Fleet Numerical Oceanography Center (FNOC) are processed and used to support worldwide operations such as joint military exercises, aerial refueling missions and many more.

In this presentation, I will provide some views on the military applications of Meteorological Satellite (METSAT) data. In particular, I will cover Air Weather Service's (AWS) use of the United States Department of Defense (DOD) METSAT, the polar-orbiting Defense Meteorological Satellite Program (DMSP). I will focus on the METSAT use at the Air Force Global Weather Central (AFGWC), the AWS centralized facility, at Offutt AFB, Nebraska and by AWS units deployed around the world. In addition, I'll point out some examples of the military mission payoffs DMSP has provided, and some insight into future DMSP enhancements.

The primary mission of AWS is to support US Air Force and US Army operations. Important keys to successful operations include target detection, identification, tracking, and destruction. The presence or absence of clouds directly impacts the ability to successfully and effectively perform these missions, and with the recent development of extremely expensive cloud-sensitive weapons systems (such as TV, infrared, and laser-guided bombs and missiles), the accuracy of cloud information assumes an even greater role.

AWS processes and uses all available data to satisfy mission requirements. Peacetime cloud-data sources include the DMSP, NOAA polar orbiting and geostationary satellites, worldwide surface and upper air data, and foreign geostationary METSATs, such as METEOSAT. The mission of the DMSP is to provide global environmental data to support worldwide US DOD operations. The sensor complement and the polar orbits are therefore tailored to US DOD needs. The 450nm orbit provides contiguous global coverage and the resolution necessary to allow detailed analysis of data.

Since the beginning of the Defense Meteorological Satellite Program, a primary objective has been to put data in the hands of decisionmakers as soon as possible. Therefore, DMSP was configured to provide data in two ways: data recorded and stored onboard the satellite for later relay when passing over a command readout site and data readout directly to a transportable van as the satellite passes within range of the van.

Data recorded aboard the satellite is eventually downlinked to readout sites at Loring AFB, Maine; Fairchild AFB, Washington and if necessary, Kaena Pt, Hawaii. The data is then passed to the Air Force Global Weather Central at Offutt AFB, Nebraska, using a communications satellite. In recent years the system has also included a communications satellite relay to the US Navy's Fleet Numerical Oceanography Center in Monterey, California. Although the concept of the physical routing of the recorded data has not changed significantly during the life of the DMSP system, the types of recorded data have increased significantly. The first mission sensor other than the cloud imager was a gamma radiation detector flown in 1971. The DMSP mission expanded in November 1972 with the launch of a satellite with a tropospheric temperature sounder and a precipitating electron spectrometer. The first operational linescan system, or OLS, a vastly improved system for cloud sensing, was flown in September of 1976.

Data can also be directly read-out by transportable vans deployed anywhere on the globe. In 1971, vans were also placed on US Navy aircraft carriers. The newest model of the transportable van is the Mark IV. One of these is located at an AWS detachment at Croughton RAFB in England. Data received at this site are further relayed to other AWS detachments in England through a tactical imagery dissemination system. An older van is located at Bann, West Germany. The data received at Bann is relayed to AWS detachments throughout Europe also through an imagery dissemination system.

Recorded data are used by the Air Force Global Weather Central to support worldwide operations such as the rapid deployment of combined or joint task forces, hurricane/typhoon positioning, and aerial refueling. Direct readout data are used by meteorologists in forward areas to support field commanders

conducting operations. Requirements for forecasts of icing, turbulence, severe weather, fields of small cell cumulus and snow/cloud discrimination demand immediate manual application of high-quality 0.3 and 1.5 nm resolution visual and infrared imagery data.

The recorded data received at AFGWC have many uses. These data are displayed on "hard copy" transparencies for use by forecasters at AFGWC. After the data are no longer operationally useful, the transparencies are archived at the University of Colorado for public use. Real-time data also flows into a completely automated processing system. The telemetry data are split off for satellite command and control as well as technical monitoring purposes. Atmospheric and space environmental data are separated and processed by sensor-unique software. Unique space environmental data are provided by the precipitating electron spectrometer, the plasma monitor, and the visual cloud sensor. The visual data and the electron spectrometer locate the auroral oval--important to forecasts for high frequency radio communications in polar regions and the high latitude early warning and tracking radar network in North America and Europe. The plasma monitor provides electron densities--essential to space system ephemeris calculations and anomaly investigations as well as ionospheric propagation for the space detection and tracking system. In addition, visual and infrared imagery are mapped into a satellite global digital data base, at 3nm resolution. This data base is constantly updated by continuous on-line processing of the imagery and is available in visual and infrared display for worldwide analysis and forecasting applications: (1) High quality displays are sent by digital facsimile to US Air Force command and control centers, the data are also relayed to a wide spectrum of other US government agencies; (2) Displays are also used as large overlays for forecast applications at our weather central; and, (3) A third application is somewhat unique to AWS, the Air Force Global Weather Central is a pioneer in using computers to blend satellite data with other meteorological data to build automated cloud analyses which, in turn, are used to initialize automated cloud forecasts to develop worldwide mission tailored products.

The automated cloud analysis model integrates the visual and infrared imagery, and remotely sensed temperature soundings, along with conventional observations, to create a 25nm resolution, three dimensional cloud analysis. Data are analyzed immediately upon receipt, while the normal global analysis is accomplished every three hours. The process is totally automated with the exception that analysis in high priority areas can be manually modified if so needed. The cloud analysis initializes the automated cloud forecast model. It is processed every three hours and forecasts cloud cover and precipitation out to 48 hours in the northern hemisphere and 24 hours in the southern hemisphere.

In summary, recorded data are used today at the AF Global Weather Central in a complex system relying on a considerable amount of computer hardware and software. Yet, the system is extremely reliable. Over 95 percent of the DMSP data are routinely processed through the system and are used in the analysis and forecast models. Data from the polar orbiting US NOAA satellites can also be processed in this manner. AWS units throughout the world receive analysis and forecast products from the weather central to support US Air Force, Army, and other US DOD requirements.

The DMSP direct readout data capability satisfies US DOD requirements for worldwide, responsive, secure, high resolution METSAT information. The system is complete and self-sufficient, and the transportable vans have their own power supply and data processing capability. In this mode, DMSP provides timely visual and infrared imagery directly to transportable vans collocated with field commanders responsible for field operations. General Momyer, USAF Commander in Vietnam, relating his experience with the DMSP system said, "As far as I am concerned, this (DMSP) weather picture is probably the greatest innovation of the war." While discussing the scheduling and launching of strike missions against North Vietnam, in his book he went on to say that, "Without them (meaning the DMSP photos)...many missions would not have been launched."

Global war is not necessary to affect the free exchange of meteorological data among nations. Increased local or regional tensions between two or more nations can stop the flow of routine conventional weather data. During the Yom Kippur War, all nations in the area of conflict stopped transmission of standard meteorological data over civil communications circuits, despite international agreements to the contrary, because weather data could possibly aid opposition commanders in making military decisions. Early in the US resupply effort of Israel, Lodi Airport at Tel Aviv was closed due to dense fog and low stratus and our resupply flow was disrupted. METSAT imagery enabled AWS forecasters to determine the weather pattern was frontal in nature and thus were able to accurately predict clearing. North Vietnam also denied their data during the Vietnam conflict. During a European war, our opponents will almost certainly stop transmitting weather data. In addition, NATO countries may stop transmitting weather data because of its usefulness to Warsaw Pact Countries. Thus, the encrypted DMSP data available at transportable vans in Europe may be the primary source of weather data for our European forces.

The United States Readiness Command's mission requires short notice deployment of a joint task force to virtually any area of the world. High quality resolution satellite data, responsive to the deployed military commander, are often the sole source of weather data in a contingency area where data are either sparse or denied. In support of US commitments to NATO, the US regularly deploys tactical fighter squadrons from US bases to allied airfields in Europe. Decisions to launch, delay, or change refueling areas, not only for the fighter aircraft, but also for the supporting tanker aircraft needed for refueling, are often based on the high quality resolution data available from the DMSP. The recent Reforger Exercise in Europe and the August 1983 Bright Star Exercise in Egypt gave AWS meteorologists many chances to exercise their training in the use of METSAT data to support deployment of forces.

A DMSP tactical van, as well as recorded data received at the AF Global Weather Central, provides coverage necessary for the Air Force weather satellite support to the Joint Typhoon Warning Center (JTWC) located on Guam in the Pacific. JTWC provides tropical cyclone positions and warnings for most

of the Pacific and Indian Oceans, from the international date-line to the east coast of Africa. Since [illegible], more than half of the JTWC's warnings in the western Pacific were based on satellite positions of tropical cyclones. In the Indian Ocean, where reconnaissance aircraft and land-based radar are rarely available, over 95 percent of the JTWC's warnings were based on satellite fixes from recorded data analyzed at the AF Global Weather Central. Tropical cyclone warnings required by military commanders throughout the Pacific and Indian Oceans, are also made available to civil and international agencies.

The examples I've just discussed highlight the extensive use of DMSP by Air Weather Service. To meet growing operational support requirements, we have programmed additional capabilities for the DMSP. Among many improvements envisioned, the space environment mission will be strengthened with the addition of both a topside ionosonde and a refined plasma density monitor for detailed profiles of electron density. The microwave water vapor profiles will allow us to determine aerial coverage and rates of precipitation over the globe. We envision these data will provide an improved cloud analysis capability and improved trafficability forecasts for commanders. Finally, increased system survivability and reliability will increase the DMSP availability and utility.

Improvements in the direct readout capabilities are also envisioned. In the future, multiple sensor data, such as microwave water vapor profiles and atmospheric sounder data, are planned to be included in the direct readout mode along with a data processing capability. These data will increase the capability of the military meteorologist to provide critical support when conventional weather data are not available. Commanders will then have the environmental data to consider immediate changes to maximize the potential of their command and control systems.

The DMSP, a system responsive to military requirements, has grown considerably during the past decade. The close interaction among the weatherman at the tactical readout terminal directly supporting the field commander, the Air Force Global Weather Central building and applying its worldwide data base, and dedicated command and control of the on-orbit DMSP satellites have provided a finely tuned system capable of responding to national security requirements. In short, DMSP and other sources of meteorological satellite data have proven to be vital to AWS's support to national defense and will continue to evolve to meet the changing needs of decisionmakers.

AD A151 864 SPACE SYSTEM APPLICATIONS TO TACTICAL OPERATIONS(U) ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT NEUILLY-SUR-SEINE (FRANCE) OCT 84 AGARD-CP-344

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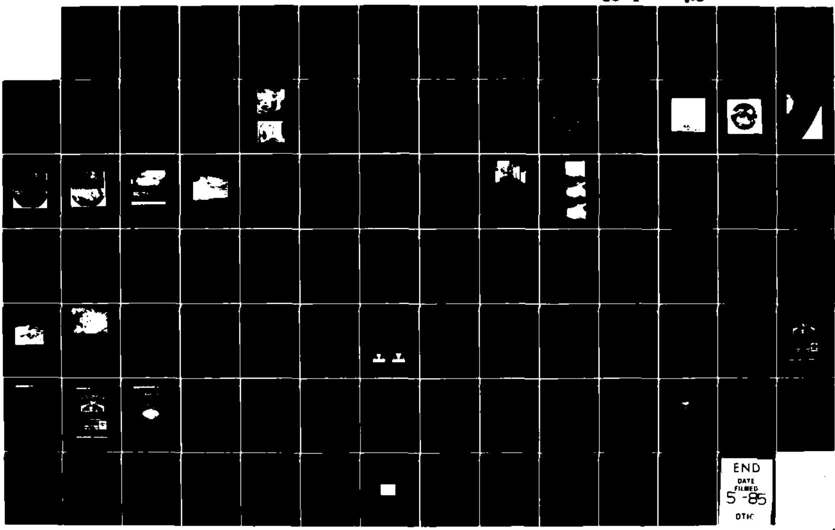

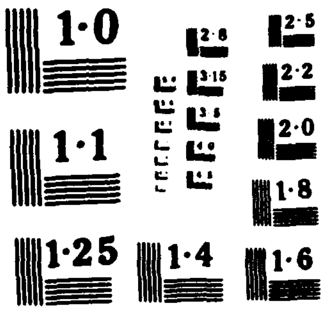
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CIVIL WEATHER SATELLITE SYSTEMS

by

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U.S. weather satellites operated by the National Oceanic and Atmospheric Administration, (1) collect and distribute qualitative and quantitative data, and (2) provide communications and relay functions for environmental and search and rescue data. Qualitative data consists of visible and infrared (IR) images of cloud and weather features. Quantitative data comprises (1) measurements of the vertical temperature structure of the atmosphere (soundings), (2) sea surface temperatures, (3) cloud motion winds, and (4) solar environmental data. Communications functions include the broadcast of data stored during orbit to special read-out stations, and the global, real-time broadcast of data to read-out stations, worldwide. Relay functions of weather satellites include: collection of environmental data broadcast from buoys, ships, aircraft, and from remote sites, for relay to central site for processing and distribution, and global collection and relay of emergency signals from aircraft and ships in distress.

This paper provides an overview of the presently operating U.S. civil weather satellites, their space and ground systems and their data distribution systems. Examples of the data products available from the satellites are provided with emphasis on their potential application to the support of tactical operations. The products from the civil weather satellites include multi-spectral imagery on several time and space scales and quantitative products that are of use in providing weather support to tactical planners.

The present DoD-Civil weather satellite cooperative arrangements are reviewed with a discussion of the "Shared Processing" arrangements currently being implemented. A brief overview of international weather satellite coordination is also provided. The paper concludes with an outlook of future trends in the development of future civil weather satellite systems.

The National Environmental Satellite, Data, and Information Service, NOAA's operating branch for all environmental satellites, operates two types of weather satellites: polar-orbiting and geostationary[1,2]. Polar-orbiting weather satellites provide global data. Two are now in orbit, with the following characteristics:

Orbit Type: Near polar, sun-synchronous

Altitude (Circular): 854 km (530 mi.) morning satellite
833 km (518 mi.) afternoon satellite

Orbit Period: 102 minutes

Orbit Times (Equator Crossing): 7:30 a.m. local, morning satellite
2:00 p.m. local, afternoon satellite

Longitudinal Separation of Adjacent Orbits at the Equator: 2821 km (1750 mi)
25° longitude

Sensor Cross Track Scans widths:
Imager - 2,800 km (1,740 mi.)
Sounder - 2,347 km (1,458 mi.)

Geostationary weather satellites provide continuous viewing of the United States and adjacent coastal waters. Two operational units are in orbit, with these characteristics:

Altitude: 35,000 km (22,300 mi.)
Orbit Period: 24 hours
GOES East: 75°W, covers ± 50° latitude and longitude around subpoint
GOES West: 135°W, covers ± 50° latitude and longitude around subpoint

NOAA-Series Spacecraft

NOAA's two polar-orbiting spacecraft, based on an earlier TIROS design called NOAA-A, B, etc., provide operational coverage of the entire Earth four times per day. They are a principal source of environmental data for the 80% of the globe that is not covered by conventional data. The purpose of these satellites is to make measurements of vertical temperature and humidity structure of the atmosphere, surface temperature, cloud cover, snow cover, water-ice boundaries, and proton and electron flux near the Earth. They have a capability of receiving, processing, locating, and relaying to readout stations data from balloons, buoys, ships, and remote automatic stations distributed around the globe. The satellites also carry a Search and Rescue transponder to be described later.

The sensor and relay systems on the NOAA-series polar satellites include:

- TIROS Operational Vertical Sounder (TOVS)
- Advanced Very High Resolution Radiometer (AVHRR)

- Space Environment Monitor (SEM)
- Solar Backscatter Ultraviolet Radiometer (SBUV)
- ARGOS Data Collection and Platform Location System (DCS)
- Search and Rescue System (SARSAT)

In addition to the normal command, telemetry, and data communications capabilities of the NOAA-series satellite, direct data readout service to users is provided via three broadcast channels:

- High Resolution Picture Transmission (HRPT)
- Automatic Picture Transmission (APT)
- Direct Sounder Broadcast (DSB)

The Advanced Very High Resolution Radiometer (AVHRR) is a five-channel scanning radiometer sensitive in the visible, near-infrared and infrared window regions. (See Table.) This instrument provides data for major data readout stations, and for Direct Sounder Broadcasts, APT, and HRPT outputs. HRPT data is transmitted at full resolution (1.1 km); APT images have reduced resolution (4 km.)

Advanced Very High Resolution Radiometer (AVHRR)

CHANNELS	WAVELENGTHS(μm)	PRIMARY USES
1	0.58 - 0.68	Daytime cloud/surface mapping
2	0.725- 1.10	Surface water delineation
3	3.55 - 3.93	Sea surface temperatures, nighttime cloud mapping
4	10.50 -11.50	Sea surface temperatures, day and night cloud mapping
5	11.50 -12.50	Sea surface temperatures

Reports from the TIROS Operational Vertical Sounder (TOVS) are a major satellite source of data for numerical weather prediction for computers operated by the National Weather Service. The TOVS is a three instrument system, consisting of:

High Resolution Infrared Radiation Sounder (HIRS/2) - a 20-channel instrument making measurements primarily in the infrared region of the spectrum (0.69 - 14.96μm). The instrument is designed to provide data that will permit calculation of (1) temperature profile from the surface to 10 mb; (2) water vapor content in three layers in the atmosphere; and (3) total ozone content.

Stratospheric Sounding Unit (SSU) - employs a selective absorption technique to make measurements in three infrared channels (all near 15μm. Data from the SSU, an instrument built and funded by the United Kingdom, allows calculations to be made of temperature profiles in the stratosphere.

Microwave Sounding Unit (MSU) - a 4-channel radiometer, makes passive measurements in the 5.5 mm oxygen band (50.3 - 57.05 GHz). This instrument, unlike those making measurements in the infrared region, is little affected by clouds. Used with the HIRS data, MSU data extends temperature profiles below cloud tops to the Earth's surface.

Data from the TOVS are available locally as a part of the HRPT transmission and on the spacecraft VHF beacon transmission, frequently referred to as the Direct Sounder Broadcast (DSB).

Another set of NOAA-series spacecraft sensors is the Space Environment Monitor (SEM) system. SEM data are used to monitor and predict solar events such as sunspots and flares, and map the boundaries of the polar auroral ovals. Similar measurements are also made by NOAA's geostationary satellites. SEM instruments include:

a. The Total Energy Detector (TED); which measures a broad range of energetic particles from 0.3 KeV to 20 KeV in 11 bands, and

b. The Medium Energy Proton and Electron Detector (MEPED); which senses protons, electrons, and ions with energies from 30 KeV to several tens of MeV.

Applications of SEM data from Polar and Geostationary satellites include:

- Prediction of the ionospheric conditions affecting radio communications and over the horizon radar systems;

- Prediction of effects of magnetic storms on electrical power distribution (particulary in the northern latitudes); and
- Prediction of radiation levels affecting high-altitude military and civil aircraft, and manned space activities such as shuttle flights.

The Solar Backscatter Ultraviolet Radiometer (SBUV/2) is a non-spatial scanning, nadir viewing instrument, designed to measure scene radiance in the spectral region from 160 nanometers (nm) to 400 nm. The data gathered are used to determine the vertical distribution of ozone in the earth's atmosphere, total ozone in the atmosphere, and solar spectral irradiance.

NOAA-Series satellites have several modes of data collection and dissemination.[3] High resolution data (1.1 km) sensed by the AVHRR imager is constantly broadcast in the HRPT channel as a stream of numbers suitable for computer gridding and processing. Some high resolution images (one-tenth of an orbit) and all sounding data are taped on-board for readout at ground stations in Alaska, Virginia, and Lannion, France.

Picture elements are also combined on-board to form low resolution images (4 km). Low resolution data from whole orbits are stored for readout. They are also processed on-board for a facsimile transmission called Automatic Picture Transmission (APT). These local images are broadcast constantly, and can be received and shown on a television screen display for a few hundreds of dollars. A more professional APT ground station system costs only \$3000-\$5000. More than 1000 APT ground stations are in use throughout the world in 122 countries.

HRPT reception is more expensive (\$300,000), since it requires a more costly radio and a computer processor to format high resolution AVHRR data into images. There are 23 HRPT stations owned and operated by U.S. Federal agencies other than NOAA. Presently, there are 46 foreign HRPT stations in countries such as Canada, France, West Germany, India, Japan, and Peoples Republic of China. Selected applications of Local Area Coverage (LAC) data illustrate AVHRR/HRPT data users:

Country	Application
Senegal	Monitoring pastoral areas for plant growth and development.
Australia	To observe surface currents in the Tasman Sea, particularly the East Australian Current.
Canada	To monitor vegetation development in two different areas of the U.S.S.R.
France	To observe oil slick movement in the Persian Gulf.
Italy	Monitor African desert locust breeding grounds.

Sounding data from the three TOVS sensors, HIRS/2, SSU, and MSU, are broadcast continually. Public interest in these Direct Sounding Broadcasts (DSB), initially was low; only seven stations were known, in five countries, after five years of DSB service. This number has grown to 29 countries recently, with the development by NOAA research laboratories of new software that permits simple calculation of soundings from TOVS raw radiances. DSB's give local forecasters and flight controllers and planners access to local area soundings spread over a region of about 2,000 by 4,000 km.

Two data relay systems are operational aboard NOAA-series spacecraft. Both use the Doppler effect occurring between the moving satellite and a quasi-fixed transmitter at the Earth's surface to permit location of the ground station. Two satellite passes, at minimum, are needed to resolve fully the station location.

(a) The ARGOS system, a platform location and data relay system, is a cooperative project among:

The Centre National D'Etudes Spatiales (CNES, France),

The National Aeronautics and Space Administration (NASA, USA),

The National Oceanic and Atmospheric Administration (NOAA, USA).

The spacecraft portion of the ARGOS Data Collection System (DCS) equipment is provided by CNES at no cost to the U.S. ARGOS collects and relays environmental data from buoys, balloons, and other platforms located anywhere on the earth's surface, and is the only environmental satellite data collection system capable of locating fixed and moving platforms.

The ARGOS system is comprised of:

- User platforms, each equipped with sensors and a platform transmitter terminal;
- Two satellites in orbit at any one time, each equipped with an on-board data collection system (DCS) ensuring platform message reception, processing, and retransmission;
- The ground data processing centers.

ARGOS data relay from Arctic and Antarctic platforms not in view of the geostationary satellites is important to the U.S., as is ARGOS platform locations for major oceanographic research programs in which drift speeds of buoys are important.

(b) To aid downed aircraft and ships in distress in remote regions, the United States, Canada, France, the USSR, the United Kingdom, Sweden, and Norway have joined together in the deployment of a search and rescue system. Thousands of emergency transmitters are already installed on commercial and private aircraft. The system detects faint distress signals and relays them via a NOAA-series spacecraft and a comparable USSR satellite, to local ground stations and on to the appropriate rescue forces. As in the case of ARGOS data relay, Doppler permits location of distress signals. More than 50 lives have been saved in the first months of operation. The United States, Canada, and France provide space and ground hardware for use on the NOAA weather satellites; the USSR provides a compatible system. Several countries provide ground readout stations. NOAA-8 and two Soviet satellites presently carry the search and rescue relay hardware.

Geostationary Operational Environmental Satellite (GOES)

Two GOES satellites, located at 75° West and 135° West longitude, observe the Eastern and Western United States and the adjacent ocean areas from their vantage points over the Equator, and have coverage zones which extend well into the Southern Hemisphere. The GOES satellites make day and night observations of weather in the coverage area, monitor severe weather events such as hurricanes and other severe storms, relay meteorological observation data from surface collection points to a processing center, and perform facsimile transmission of processed graphic and imaged weather data (WEFAX) to field stations. The satellites also monitor the condition of the magnetic field of the Earth at geostationary altitude and measure the energetic particle flux in the vicinity of the satellite, and observe X-ray emissions from the Sun, transmitting these observations to a central processing facility. These latter measurements are made through the instruments collectively called the Space Environment Monitor (SEM). The satellites' sensor and data relay systems include:[4]

- Visible-Infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder (VAS)
- Space Environment Monitor (SEM)
- Data Collection System (DCS)

The VISSR sensor provides operational day-night imaging of the Earth. When it operates in the VAS mode, it provides experimental sounding measurements. The VAS mode slows down the VISSR's imaging rate of Earth scanning. In addition to the normal communications links, users can receive GOES data directly from the satellite via:

- VAS Direct Broadcasts;
- VISSR Image Broadcasts;
- Weather Facsimile Service (WEFAX).

Geostationary data is unique in satellite meteorology in that images from almost one-third of the Earth can be obtained in a short time. A whole-disk image requires 20 minutes of scan time. Alternatively, since the viewed area is never out of sight, partial images may be scanned, in lieu of whole-disk images, as often as once per five minutes. For example, a nascent tornado-producing storm can be observed, and threatened areas alerted, while the storm is in progress. From one visible and 12 infrared channels, (0.55 - 0.72 μm, 3.945 - 14.73 μm), sequential VISSR images permit meteorologists to observe regional cyclone development and movement. Apparent cloud movement between images is used for calculation of "cloud motion winds."

VAS mode soundings have great potential for the future, since they, like images, can be scanned frequently for selected areas of the full disk, but a full disk sounding requires 13 hours. At present, VAS soundings have not reached the quality of polar orbiter TOVS soundings, since they are based on fewer IR channels, with no microwave sensors for temperatures below cloud levels, and have a larger field-of-view.

Space Environment Monitor (SEM) System

The GOES SEM system measures the variability of:

- The Earth's magnetic field
- The flow of emission of X-Rays from the Sun
- The strength of concentration of particles (protons and electrons) from the Sun

SEM data are processed and applied by the joint NOAA/USAF Space Environment Services Center, Boulder, Colorado. Uses include prediction and monitoring of:

- Sun spots, solar flares, and solar storms

- The effects of solar activity on the Earth's magnetic field, variations in Polar Auroral Belts, and intensity of near Earth radiation belts

Other Applications include predictions of:

- Transmission conditions of ionospheric radio and over-the-horizon radars;
- Effects on electric power transmission grids;
- Radiation Levels Affecting:
  - High altitude civil and military aircraft operations;
  - Manned space activities (such as shuttle flights).

GOES Data Collection and Relay Systems

The GOES Data Collection System is a multi-channel transponder system that allows messages from remotely-located data collection platforms to be relayed via the satellite to a central processing facility.[5] Platforms include sensors for flash floods, tsumanis, earthquakes, winter snowfall, etc.

Another message relay function is the GOES Search and Rescue transponder. Although emergency reports can be located only by Polar-Orbiting spacecraft, the GOES SAR will allow emergency reports to be sent at all times, without delay, whether or not a polar satellite is overhead.

Weather Facsimile (WEFAX):

WEFAX uses the GOES spacecraft to relay low resolution satellite imagery and meteorological charts to properly equipped ground stations in the western hemisphere.[6] Many countries have no other access to satellite imagery, as well as to standard meteorological charts from the World Meteorological Center, Washington, D.C.

The WEFAX transmission frequency is common with the frequency used by the European Space Agency's METEOSAT and Japan's GMS spacecraft facsimile service and so provides near global access to WEFAX service. This global availability is especially important to commercial shipping and for military operations.

There are 190 known WEFAX receiving stations, more than 100 of them operated by users in foreign countries.

Satellite Data Products

Satellite data products vary from mapped values produced by a few simple calculations, to soundings for which complicated algorithms must be employed.[3,7] For a typical product, two or more channels of radiance values are used to deduce correct temperature values. Temperature values may then be displayed in a linear grey scale (as in "normal" photography), or the grey scale may be "stretched" to emphasize selected values. To show a crop-freeze line, for example, areas with temperatures warmer or colder than freezing are shown in subdued tones; temperatures near freezing are mapped in sharp contrasts.

Polar-Orbiting Spacecraft, Data Products:

Soundings are calculated from TOVS data. Two NOAA-series spacecraft provide raw radiances for some 16,000 soundings a day, globally, from the surface to an altitude of 65.5 km. Soundings, derived from an average field-of-view of about 40 x 40 km, includes temperature, water vapor (at three levels), and total ozone.

Sea Surface Temperature (SST) is calculated worldwide for a field-of-view of 8 km, from AVHRR radiances. SST plots are used to locate ocean thermal mass boundaries for commercial fisheries, for finding ocean fog banks dangerous to shipping, and to position ocean currents (like the Gulf Stream) of interest to ship route planners.

A vegetation index is mapped for land regions of the Earth, using AVHRR Channels 1 and 2. While this product primarily shows green areas of productive farm lands, lower index values reveal encroaching deserts, potential forest fire areas, insect growth and migration regions, and surprisingly, some oil-spill slicks. This index is widely used by the U.N. World Health Organization, and the U.S. Department of Agriculture.

Global ice coverage is calculated weekly by a joint NOAA-Navy team, using AVHRR and other data. For the Polar and Alaskan regions, ice coverage is mapped to show age and thickness, Great Lakes winter ice is also mapped.

Volcanic ash, floating in the stratosphere, has proved to be a hazard to jet aircraft. One flight near Indonesia has twice suffered engine stoppages while passing through the ash plume from eruptions of Galunggung and Una Una. AVHRR data facilitates global surveillance for ash hazards.

The heat budget of the Earth shows the balance between solar energy falling on the Earth, and the outgoing terrestrial (thermal) radiation. AVHRR visible data are used to determine the albedo of the

Earth (that is, the whiteness of the surface, oceans, and clouds), and outgoing radiation measured in the IR "atmospheric window." Heat budget values are used in climate studies. After a history of values is archived, it may be possible for analysts to predict seasonal or annual weather on the basis of trends in heat budget balance values.

Geostationary Satellite Products:

From geostationary orbit, the VAS provides measurements of the atmosphere's temperature and moisture more frequently than polar orbiter data. These measurements can be obtained over the U.S. and adjacent waters every hour with VAS, whereas they are obtained every 12 hours with a polar orbiter. Also, all the measurements over the U.S. can be acquired in one hour, whereas five hours (three consecutive orbits) are needed to acquire these data from polar obiters. The temporal continuity and frequency VAS images and soundings are especially useful for (1) detecting areas where atmospheric conditions favor the development of severe weather (e.g. warm moist air under colder dry air); and for (2) monitoring the rates of change of these conditions.

VAS soundings over data-sparse regions are used as input to numerical models. In this regard VAS soundings can be used to initialize the large scale models more frequently and as input to regional or small scale models currently being developed. VAS soundings and products derived from them (temperature and moisture analyses, instability trends, etc.) are undergoing extensive evaluation by the National Meteorological Center, the National Hurricane Center, the National Severe Storm Forecast Center, and the Program for Regional Forecasting Services.

Snow watch.

In the mountain states of the U.S., values for a winter Snow Watch for 30 run off basins are now calculated regularly from satellite imagery. Using previous years' runoffs, analysts can relate snowfall area occurrence of precipitation to snow pack water content. As Spring arrives, the retreat of snow cover discloses snow melt rates. In the floods of 1983, snow analysis, confirmed by GOES/VAS sensors, provided guidance for flood management actions.

Cloud Motion Wind Vector Fields:

Wind vectors are estimated by a computer technique that measures apparent low-level cloud motions between consecutive GOES images, using infrared image data over ocean areas.[8] Upper level motions are measured manually on a computer interactive system. Approximately 1200 Wind Measurements are made and delivered three times per day to users, who include:

National Meteorological Center (Camp Springs, Maryland);

U.S. Air Force Global Weather Central (Offutt AFB, Nebraska);

U.S. Navy Fleet Numerical Oceanographic Center (Monterey, California).

Sea Surface Thermal Composite:

Sea surface composites are used for mapping water masses, fronts, and eddies. They are useful for locating favorable fishing grounds, for ship routing, and for determining underwater sound propogation. Daily infrared temperature composites are produced from four daytime images from both GOES West and GOES East. Composites are available to NOAA computer terminal users and are distributed by the National Weather Service. The U.S. Navy is currently the biggest user.

Products produced from geostationary data involving grey-scale distortion "stretching" include: Hurricane and thunderstorm core designation, cloud depictions, snow enhancement, cloud top pin-pointing, snow melt, freeze line designation, location of water mass boundaries, morning fog location, costal upwelling location, and depiction of general meteorological features.

Other derived geostationary satellite products include:

- Rainfall estimates - Estimates of heavy rainfall are depicted from enhanced GOES satellite imagery, and are used for flash-flood forecasts.
- Hurricane Classification - Hurricanes are classified and tracked without hiatus.
- Satellite Interpretation Messages describe the general synopsis of the weather affecting the U.S. and are supplied two to eight times per day.
- Tropical Storm Bulletins - Coded messages depict the locations of vortices with tropical history for the Atlantic, Pacific, and Indian Oceans.

Defense Department Spacecraft

Another source of data for civil and Defense Department weather forecasting are satellites of the Defense Meteorological Satellite Program (DMSP). Like the NOAA-Series platform, the DMSP spacecraft are polar orbiters with an array of sensors comparable to the NOAA Series: The Operational Linescan System (OLS) has multiple visible and infrared channels for imagery (0.56 km regional FOV, 2.78 km global FOV),

cloud location and calculation of sounding. Passive microwave sensors for soundings and images are also provided. Space environments are monitored by sensors comparable to the NOAA-series SEM. NOAA-series and DMSP satellites utilize many similar components, including the main frame "bus."

International Weather Satellites[9]

In addition to the U.S. polar and geostationary satellites (GOES-East and West, located at 75° and 135° west longitude), four other geostationary satellites, sufficient for a continuous global review of mesoscale and large scale weather features, are in operation or planned. All provide visible and infrared imagery, data collection, and WEFAX (except India's INSAT):

International Geostationary Satellites

Name	Operator	Location (Longitude)
METEOSAT	EUMETSAT and the European Space Agency	0°
GMS	Japan	140°E
INSAT	India	72°E
GOMS (Planned)	USSR	74°E

Russia's polar orbiter METEOR is the only low-orbit spacecraft now supplementing data provided by the U.S. NOAA-series system. Several countries have plans for Low Earth Orbit (LEO) spacecraft for flights later in this decade; these are primarily for land and ocean surface observations, rather than meteorology.

Data Users

Data from U.S. meteorological satellites have many other users in addition to the NOAA National Meteorological Center, the U.S. Air Force Global Weather Central, and the U.S. Navy Fleet Numerical Oceanographic Center. There are 23 HRPT stations operated by U.S. Federal agencies other than NOAA. In addition there are 46 foreign HRPT stations worldwide. Seven known DSB stations are operating in five countries; more are expected, as new software becomes available from NOAA researchers, to permit sounding calculations to be made using table-top computers. APT transmissions require only a simple receiver and a small fascimile machine. Over 900 APT stations are known, in 122 countries. Like APT, the GOES WEFAX requires only the simplest of receivers and facsimile machines. As a result, WEFAX users are found throughout the Western Hemisphere and Pacific Ocean regions. Almost 200 are in operation. Since the menu of WEFAX frames includes AVHRR images, GOES images and National Weather Service products (forecast maps), many have secondary distribution via national networks (in Central and South America) and via Meteosat to European Countries.

Department of Defense Data Users

Polar Satellites:

Imagery from the AVHRR is a primary backup and source of supplemental data for the DoD. The USAF operates the Defense Meteorological Satellite Program for primary weather support to the U.S. armed forces. The Defense and civil metsat programs are mutually supportive. Data and products are exchanged freely and critical support is provided by mutual backup in the event of system failures.

All NOAA polar metsat data are transmitted in real time from NOAA ground stations via a commercial communications satellite to the Air Force Global Weather Central (AFGWC) at the Offutt AFB, Nebraska, and the Fleet Numerical Oceanographic Center (FNOC) in Monterey, California. The AFGWC includes the NOAA-series imagery data in their objective global 3-D cloud analyses which are input to their global numerical cloud prediction models, and prepares tailored mapped projections of the imagery for special appplications. FNOC includes the NOAA imagery and sea surface temperature products in their global ocean forecasting program.

The NOAA/USN Joint Ice Center in Suitland, Maryland, uses the high resolution visible and infrared images in analyzing ice conditions over the ocean areas and the Great Lakes. The Navy prepares detailed ice analyses and forecasts for support to Artic Ocean operations and Antarctic resupply missions.

Geostationary Satellites:

GOES imagery from both East and West satellites are received directly at FNOC and AFGWC in real time. These centers use the data for routine and special forecasts for route and terminal forecasts, severe weather warnings, and for major Naval and air movements are training exercises. The cloud motion winds are used in the numerical forecast models at both centers. Data from the civilian-operated Japanese GMS and European METEOSAT are relayed to the DoD after acquisition by NOAA.

Polar Satellites:

The DoD operates portable surface receivers equipped to acquire both APT and HRPT data from the NOAA-series satellites. This equipment is deployed at 12 Air Force sites, 9 Navy installations (both on ships and at fixed facilities), and 5 units are available for deployment by the Marines. Data acquired at these stations support tactical and theater operations and training exercises. The Navy and the Air Force also provide weather support to allied forces during joint exercises through these deployed ground receivers. A program now under expansion by the Air Force is the use of vans as ground station terminals for both direct DMSP and HRPT reception. Some 16 of these are scheduled for operation by 1987. NOAA and DMSP imagery are the primary sources of data for the Navy and Air Force in providing weather and oceanographic support to units operating in the Southern Hemisphere and in remote areas where conventional sources of data are sparse and often unreliable. The Joint Typhoon Warning Center on Guam is a major user of polar Metsat imagery for the tracking and forecasting of tropical Pacific storms.

Geostationary Satellites:

Naval ships deployed in the Atlantic and the Pacific acquire the GOES WEFAX broadcasts of satellite imagery and routine weather maps produced by NMC. NOAA acquires Japanese GMS data in Hawaii and Guam for use by the DoD. The GMS imagery is used for tracking and forecasting typhoons.

NOAA-DoD Shared Data Processing[10]

In 1985, NOAA and the DoD will begin operation under a shared processing agreement which will distribute the ground processing of data from both DMSP and NOAA metsats across major operational processing centers. The AFGWC will process and map all visible and infrared imagery; the FNOC will process oceanic parameters and products; and NOAA will process all sounding data from both DMSP and NOAA satellites. As each center processes the data and products in its area of expertise and responsibility, domestic communications satellite links are used to distribute the outputs in real time to the computers of the other two centers. Shared data processing will provide mutual access and backup to AFGWC, FNOC and NOAA data bases.

A major gain of shared processing, planners believe, will be (1) a saving in overall processing costs and (2) a closer linking of the three major U.S. weather-related facilities. More data will be shared; NOAA, for example, will for the first time, have access to DMSP microwave sounder and imagers (SSMT, SSMI) to supplement the SSU and MSU components of TOVS. More data channels will link the three facilities; both commercial data relay satellites and land telephone lines will be used. Closer liaison among the three should reduce the differences in data formats and software peculiarities. Products to be produced by each center include:

Shared-Processing Data Products

Agency	Products
FNOC	- Sea surface Temperature - Brightness Temperature Fields - SSMI Environmental Parameters (ocean surface winds, ice cover, precipitation, cloud water content.)
AFGWC	- Satellite Global Data Base (mapped imagery) - Cloud Analysis Data Base - SSMI and SSMT Raw Data Files
NESDIS	- Atmospheric Temperature Soundings - Atmospheric Water Vapor Soundings

Weather Data Support for Tactical Missions

This summary of civil satellite systems shows that tactical units have a variety of sensors and satellite broadcast services available to them for mission use:

- GOES weather facsimile WEFAX reception requires little space, power and cost, and over a period of hours supplies a menu of local and regional weather scenes and computer-generated forecasts.
- Worldwide, APT broadcasts from NOAA-series satellites can supplement coded transmissions from the DMSP spacecraft to give low-resolution (4 km) images of the immediate region. HRPT broadcasts cover the same area with 1.1 km resolution images of local weather. DSB services, using new retrieval software, will allow field units to determine atmospheric stability aloft, without a need for weather balloon releases. Local and regional forecasts can be inferred from the DSB soundings, along with an estimate of radar and UHF radio propagation paths, for the region.
- Since DMSP and NOAA satellites are complimentary, the combined metsat system now provides field forces with six or more regional views of weather, worldwide. (More than six, if more than one DMSP Polar orbiter is operational.) More frequent views of hemisphere-wide weather patterns are available to forces operating anywhere from the Azores to Guam.

- Even today, before Shared Processing links more closely the forecasting centers of NOAA, the Air Force and the Navy, each center has a capability to provide forecast products to support the missions of the two others, in event of failures of satellites or processing capabilities.

- Throughout the world, U.S. and allied forces have the option of deploying Data Collection Platforms, such as automatic weather stations, on land or sea. Data relay would be effected by NOAA-series polar orbitiers or GOES spacecraft in the Western Atlantic or Eastern or Central Pacific.

- With NOAA acting as the data relay channel, U.S. and allied armed forces have access to weather images from European and Japanese geostationary spacecraft, thus enlarging the areal coverage of weather imagery available to them.

- Many satellite data products, relating to rainfall or drought, crop coverage, snowpack, ice coverage, and storm movement, have immediate application to the activities of field forces.

Future of the Civil Meteorological Satellites

Commercialization[11]

At the present time, the sale of the civil meteorological satellites to the private sector is under active consideration. One of the conditions of this sale, if it indeed takes place, is that the commercial operator must show how the national security contributions of the civil systems will be maintained unimpaired. This stipulation should ensure that the applications of the present civil weather satellites to the tactical military planner described in this paper will remain available for the foreseeable future.

Future Systems

A recent review of civil needs for improvements in future NOAA satellites has resulted in the proposed changes outlined below which are presently being sought through the budget process:

GOES-Next:[12]

The improvements sought in the GOES series, to be launched in 1990, are:

- Separate or independent imaging and sounding capabilities.

- Routine (30 minutes or less) imaging in five spectral channels;

CHANNEL	SPECTRAL BAND	RESOLUTION
1	0.55 - 0.75	1 km
2	3.80 - 4.00	4 km
3	6.50 - 7.00	8 km
4	10.20 - 11.20	4 km
5	11.50 - 12.50	4 km

- Improved IR Image Resolution from 8 km to 4 km.

- A separate sounder with 14 or more channels similar to the HIRS sounder on the polar orbiter.

- A separate WEFAX transmitter to permit full-time WEFAX broadcasts.

NOAA-Next:

The planning for the next NOAA-series spacecraft, to be launched in 1990, is now underway.[13] Under consideration are the following components:

- A 20-channel Advanced Microwave Sounding Unit.

- Continuation of the:

  - SEM,
  - ARGOS,
  - Search and Rescue Mission,
  - SBUV.

- Addition of a 4-channel (visible) Ocean Color Imager.

- Improvements in Direct Broadcast Services

- Improvements in the AVHRR:

  - Visible calibration;

- Addition of one or more channels (e.g., 1.6 μm and 6.9 μm);

- Improvements in spectral response of all channels;

- Increased resolution of the visible channels to 500 m.

Next-Satellites and DoD

A comparison of present and planned specifications shows evolution, rather than a dramatic change. Even so, the changes are significant: For the "Next" polar satellites, a shift to a microwave sounder is expected. IR sounders could be phased out after a period of overlap operation to establish the credibility of the microwave sensors. No comparable movement away from IR sensors is seen i the GOES-Next requirements. Rather the changes are for an improvement in spacial resolution for visible and IR channels (from 8 to 4 km), and for more rapid soundings capability. Gains in sounders will result from an enhanced capability for the data processing system to find holes in cloud decks through which stratosphere-to-surface IR soundings can be calculated. Microwave sounders are not scheduled, due to the cost of microwave sounder antennas for use at the geostationary distances. The most probable scenario for NOAA and DoD metsat operation is for closer cooperation in the funding for development of both sensors and spacecraft (frames, power supplies, etc.).

Thus in the "Next" decade, we see improved resolution for images from GOES platforms, and improved radiance values for all-weather soundings worldwide, from the polar platforms. The expected result of this data base enlargement is improved shortrange forecasts in the Western hemisphere, and more accurate large-scale (multi-day) forecasts, over the whole Earth.

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METEOROLOGICAL AND OCEANOGRAPHIC SUPPORT DURING THE FALKLANDS CONFLICT

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SUMMARY

During Operation Corporate the United Kingdom faced the task of making opposed landings on South Georgia and the Falkland Islands 8,000 miles from the home base in the advancing southern winter. Meteorological and oceanographic support of a high standard was provided throughout the conflict because of the availability of data from orbiting (NOAA-6 and NOAA-7) and geostationary (GOES-E and METEOSAT) weather satellites.

The Meteorological Office 15-level global atmosphere numerical model was brought into routine use to cover the South Atlantic, four months ahead of schedule. Satellite temperature soundings (SATEMs) from the Tiros Operational Vertical Sounders (TOVS) on NOAA-6 and NOAA-7 provided essential data for the numerical model. Under a special arrangement with the United States at a later stage in the conflict successive NOAA-6 and NOAA-7 Advanced High Resolution Infra-Red (AVHRR IR) passes over the South Atlantic and South America were combined into composite pictures and the data was transmitted to the United Kingdom. The composites were used to select areas of special interest which were then examined at up to full resolution. Processed data included multi-spectral colour images and sea surface temperature profiles which were invaluable in positioning units of the Task Force to take maximum advantage of oceanographic, sea fog or cloud conditions. Some of the ships were equipped with Automatic Picture Transmission (APT) reception facilities and the meteorological unit supporting the Royal Air Force on Ascension Island was equipped both with orbiting and geostationary satellite APT reception.

Following the occupation of the Falkland Islands and South Georgia by Argentina on 2 April 1982 the United Kingdom faced the formidable task of recovering its sovereign territory 8,000 miles from the home base in the face of the advancing southern winter. Weather and oceanographic conditions proved to be major considerations in military decision-making at every level of command. There was a heavy demand for detailed climatological advice and for forecasts on timescales from three hours or less to three days or more ahead. As was to be expected, Argentina suppressed meteorological data from her military airfields and there were no observations from South Georgia or the Falkland Islands. There was little data available from ships in the South Atlantic, apart from our own Task Force. Nevertheless, meteorological and oceanographic support of a high standard was provided throughout the conflict largely because of the availability of data from orbiting (NOAA-7) and geostationary (GOES-E and METEOSAT) weather satellites.

It was recognised from the beginning that forecasting for military operations in the South Atlantic would prove very difficult in the absence of reliable computer forecasts for the southern hemisphere from our own sources. Before the crisis arose the numerical forecasting model then under development in the Meteorological Office at Bracknell was capable of producing forecasts only down to 30°S. However, the data assimilation was being performed globally and a basis was therefore available for the preparation of global numerical forecasts, with particular emphasis on South America and the South Atlantic. A great deal of computer programming over the weekend following the Argentinian invasion resulted in the availability throughout the conflict of routine twice-daily computer forecasts for the South Atlantic, verifying up to three days ahead. Few adjustments to the forecast model were subsequently needed and it proved to be so well constructed that little use was made of global forecast products from the United States which were made available to the United Kingdom meteorologists and oceanographers later in the conflict. That back-up support was, nevertheless, highly valued and much appreciated. The only significant failure in the ability of Bracknell to provide routine numerical products resulted from a computer overheat which was traced to a cooling water problem.

Even in normal times little conventional surface or upper-air data is available from the South Atlantic and the computer data assimilation programme depends heavily on satellite temperature soundings (SATEMs) from the polar-orbiting NOAA-7 series of satellites. A comparison of the maximum possible coverage of radiosonde data from the Southern Hemisphere (figure 1), which in practice is never achieved, with the coverage of actual SATEM data received over a six-hour period three hours either side of 1200 GMT on 24 April 1982 (figure 2), taken from the World Meteorological Organisation (WMO) Global Telecommunications System (GTS), shows how significant SATEM data is to the data input for computer analyses and forecasts over the data-sparse South Atlantic. The example is fully representative of the routine coverage of SATEM data available to Bracknell throughout the Falklands conflict.

As an example of the quality of the Bracknell computer products produced by the numerical model which was still under development at the time, the 24-hour numerical forecast verifying at 1200 GMT on 25 April 1982 (figure 3) should be compared with the analysis for the same time (figure 4). Successive numerical forecasts, run with new data at 12-hour intervals, indicated that a short spell of less disturbed weather would affect South Georgia on 25 April as a surface ridge of high pressure between two fast-moving depressions moved quickly eastwards across the island. South Georgia was recaptured on 25 April 1982.

Apart from SATAMS, composite high-resolution infra-red pictures compiled from successive passes of NOAA-7 were available to the meteorologists and oceanographers in the United Kingdom within about six hours of the time of the central pass. The techniques for presenting the satellite data for environmental forecasting, developed at the Royal Aircraft Establishment at Farnborough in the United Kingdom, are described by Lodge and Boxwell in the next presentation. The main application of the infra-red composite pictures was in oceanographic forecasting which will be described by my colleague Captain John Marsh. However, the matching of composite satellite sequences with successive weather charts by the meteorologists in the United Kingdom, both at Bracknell and at Northwood, focussed attention on the rapid variability of the weather over the South Atlantic which was being experienced at first hand by their colleagues embarked with units of the Task Force and by the Task Force commanders.

The complex and rapid development of weather in the South Atlantic is illustrated by first comparing the surface analysis for 1200 GMT on 7 June (figure 5) with the analysis for 1200 GMT on 8 June 1982 (figure 6), when you will see that a depression moved from Cape Horn to a position south of the Falkland Islands. A comparison of the composite NOAA-7 infra-red satellite pictures only fourteen hours apart at central pass times of 0556 GMT and 1944 GMT on 8 June 1982 (figures 7 and 8) shows how rapid was the development of the associated cloud systems. The earlier composite shows the marked drying effect of the southern Andes on the westerly airstream throughout 7 June. The later composite shows the almost explosive development of cloud and associated weather in the Falklands area during 8 June as the previously westerly flow across the Andes is replaced by a southwesterly over Cape Horn and the open ocean between the Cape and the Falkland Islands, bringing a plentiful supply of moisture into the circulation of the depression. The effect of orography is well illustrated by comparing the earlier surface pressure analysis (figure 5) with the earlier composite satellite picture (figure 7) and the later surface analysis (figure 6) with the later composite satellite picture (figure 8).

Detailed forecasts for long range reconnaissance, supply and attack air operations flown out of Ascension Island were provided by a military meteorological unit on the island, manned by reserve officers from the Meteorological Office and equipped with receivers for both polar-orbiting and geostationary weather satellites in addition to radiofacsimile and radioteleprinter reception. The identification of cloud-free levels and areas from weather satellite visual and infra-red pictures was and remains, with the airbridge to the Falkland Islands still in operation, a major consideration in the planning and conduct of complex in-flight refuelling operations. The mix of weather and oceanographic forecasting essential to the successful conduct of operations by units of the Task Force in the vicinity of South Georgia and the Falkland Islands will be described by my colleague, Captain John Marsh, of the Royal Navy...............

I should first introduce an unlovely word that has been invented by the Royal Navy to describe people like me whose job it is to provide meteorological and oceanographic support - I am a METOC Officer. Specifically, since February 1982 I have been the Assistant Chief of Staff (METOC) to Commander in Chief, Fleet, responsible for the provision of METOC support of Fleet operations worldwide. This includes the support of Submarines as well as surface ships and the oceanographic support needed by the RAF's Maritime Patrol aircraft for their ASW operations. Support is provided by the Fleet METOC Centre at the CINC's Headquarters at Northwood, near London, working in harness where appropriate with the small METOC teams that are embarked permanently in some ships.

As long ago as 1969 the Royal Navy identified the requirement for ships with embarked METOC teams to have terminals to allow direct read out of imagery from the polar-orbiting weather satellites. Procurement, however, was hit by successive cuts in funding so that at the outset of Operation CORPORATE only three ships were so fitted all of which, as it happens, were closely involved. On the scene at the outset was the Ice Patrol ship, HMS ENDURANCE; with the Task Group were the two carriers HMS HERMES and HMS INVINCIBLE. Although relatively limited in their capability these three sets were to provide invaluable APT imagery to assist the On-Scene Commanders in tactical decision making. Today I am happy to be able to tell you that procurement of 12 new terminals of a much improved capability is well advanced and that prospects for a further buy are looking good. Other ships involved which had embarked METOC teams but no satellite terminal were HMS INTREPID, FEARLESS, BRISTOL, ANTRIM, GLAMORGAN, BROADSWORD and BATTLEAXE.

The Fleet METOC Centre relied on 3 main sources of data:

a. The analyses and forecast sea level pressure charts produced by the Bracknell computer.

b. Weather reports from operational units.

c. The digital data stream from NOAA-7 processed by RAE Farnborough using techniques described by Lodge and Boxwell in the next presentation.

Using all its sources of data the Fleet METOC Centre produced 24, 48 and 72 hour forecast surface weather charts used to brief decision-makers in the UK at Fleet headquarters and in the Ministry of Defence and sent to the METOC teams with the Task Force to be the basis for their medium range forecasts. With hind-sight it is clear that to attempt 72 hours was over-ambitious.

ASW Ops were carried out by ships, helos and submarines searching for the 2 quiet diesel Submarines in the Argentine ORBAT which could, hypothetically, have posed a threat to the Task Group. Compared with the North Atlantic there was a very high reverberation level caused by the teeming marine life - to quote one METOC Officer on the spot, "the sea was like soup". Against a high level of background noise detection

[illegible] against [illegible] targets would always be low. Once in the area the METOC teams relied on their own bathythermograph measurements as the primary source of oceanographic data but on the Fleet METOC Centre for infra-red satellite imagery to locate and track regions of marked horizontal gradients of sea surface temperature (SST). These SST gradients were to prove of great importance for weather forecasting as well.

In some key elements the weather experienced by the Royal Navy in Operation CORPORATE was significantly different from that in the climatology, which is largely based on observations at Port Stanley and Grytviken. Some statistics which relate to the 45-day period from the arrival of the Task Group are of interest. At sea it was about as rough as had been expected, with sea state 5 or higher for 51% of the time, but not as cold. The incidence of fog and of low ceiling was an order of magnitude higher than had been expected - HMS INVINCIBLE was in fog for no less than 15% of the time. The dominant characteristic was the extreme rapidity with which the weather changed from fair to foul and back again. The METOC teams in the ships were stretched to the limit of their capability to meet the constant demand for short-term forecasts in support of carrier and helo operations. Fog is good to hide in but bad to land on a carrier in - it is also tricky to forecast correctly. Forecasting fog at sea requires a knowledge of the local variability of sea surface temperature - ½°C can mean the difference between fog and good visibility. At Northwood we were able to build up a comprehensive SST chart from the satellite imagery to send to the METOC teams in the Task Group. The final pay-off came when Admiral WOODWARD moved the line of approach of the long run-in to the Amphibious Landing some 6 nm to one side to put it in colder water to increase the chance of being cloaked by fog or low cloud.

Although the RAE system could zoom in to produce images of small areas, for our purposes at Northwood we concentrated on images showing development over a larger area than just the Falklands. For example, an image showing the edge of a frontal cloud system clearing the Falklands from the west might show also the next about to move east from Argentina and would define the window of clear skies between the two. Such a window would bring a high risk of air attack.

In addition to SST estimates and images of cloud cover, information about sea-ice derived from the satellite imagery was to prove of significant operational value. For example, the decision to send a [illegible] frigate to S Thule was based on the satellite images which showed that the advancing pack ice was still some [illegible] nm to the south of S Thule at the time.

Today at Northwood we are no longer in receipt of S Atlantic AVHRR data but we are in receipt of line of sight AVHRR data which cover most of the NATO area of operational concern to CINCEASTLANT. The RAE system is a vital tool in use by the Fleet METOC Centre to produce oceanographic support for ASW operations, among which the surveillance of Soviet S/M as they exit from their Northern Fleet bases into the North Atlantic has a high priority.

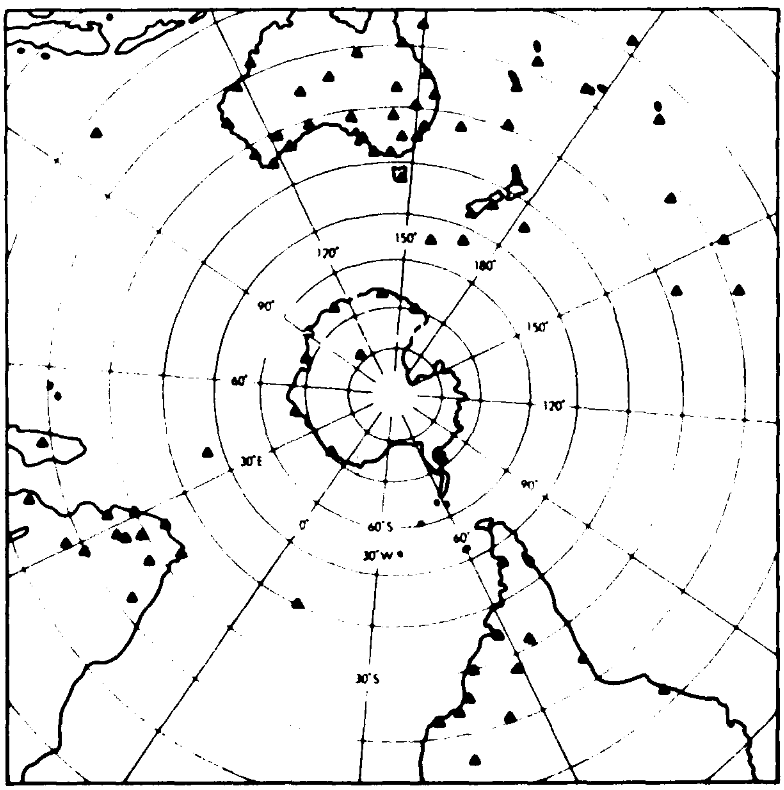
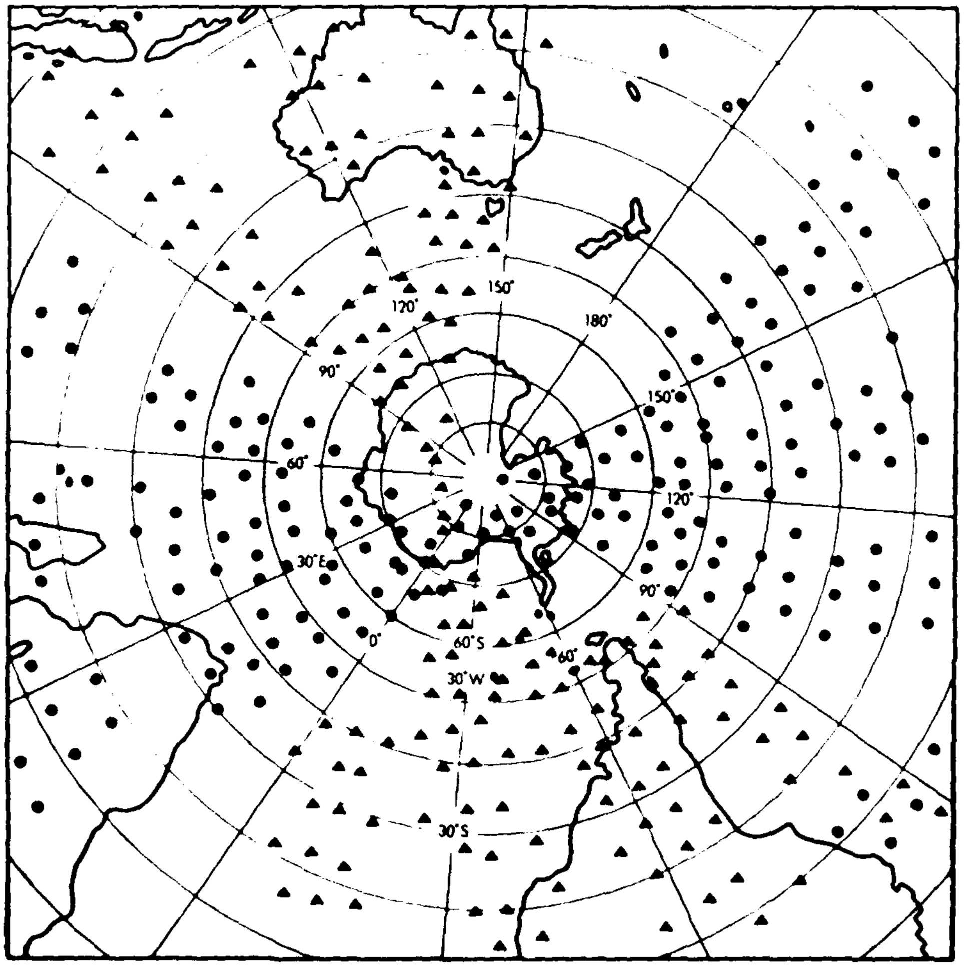


FIGURE 1

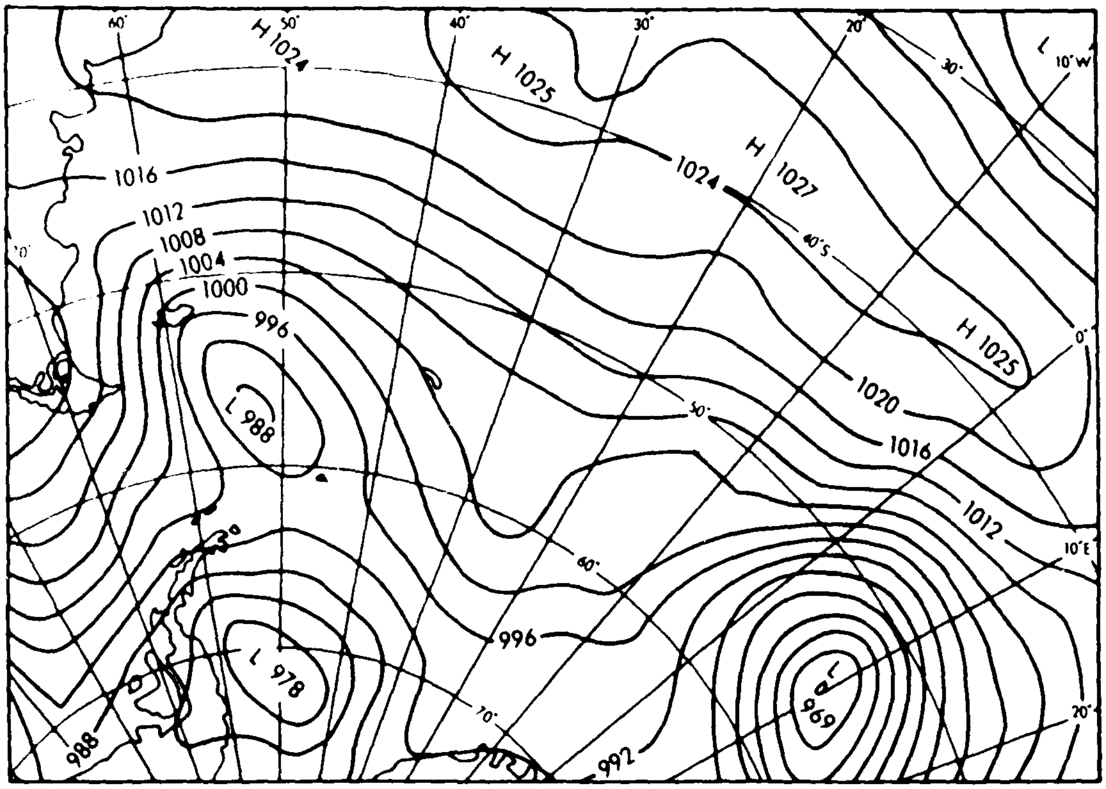
MAXIMUM COVERAGE AVAILABLE FROM SURFACE-LAUNCHED RADIOSONDES

FIGURE 2

SATELLITE TEMPERATURE SOUNDINGS (SATEMS) FROM
NOAA-6 AND NOAA-7
received during 6 hours ending 0300 GMT on 24 APRIL 1982



▲ = NOAA-6 ● = NOAA-7



24 HR

FIGURE 3

COMPUTED FORECAST FOR 1200 GMT 25 APRIL 1982 (MSL PRESSURE)

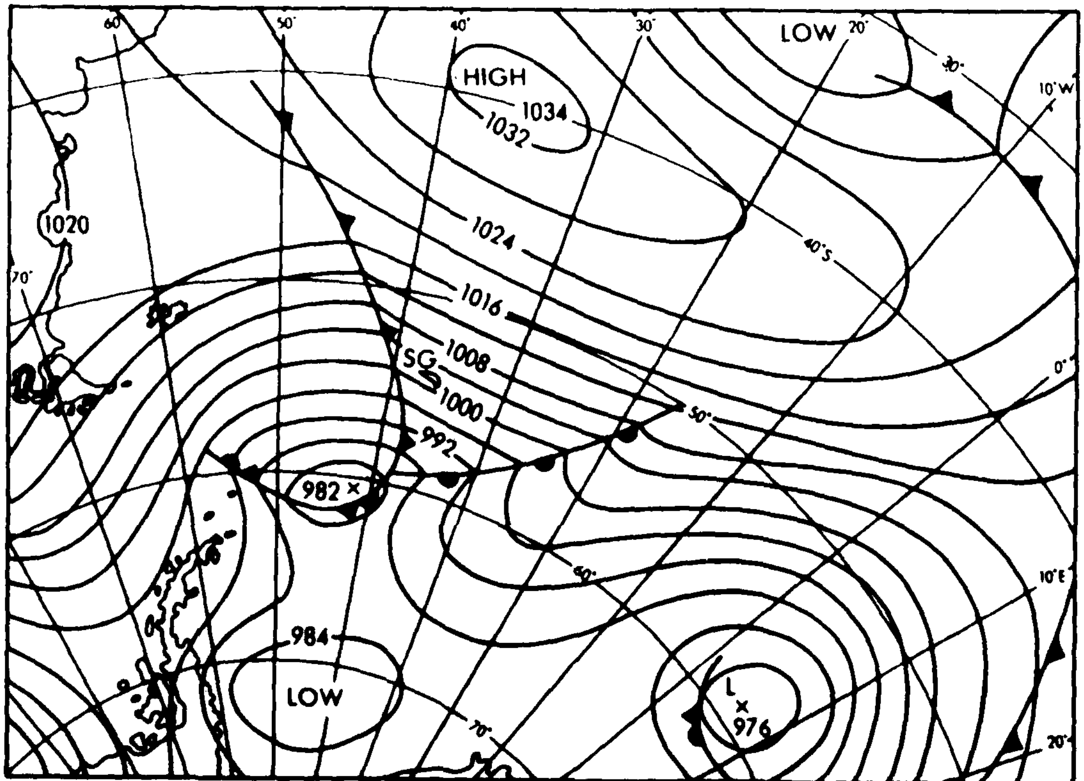


FIGURE 4

ANALYSIS FOR 1200 GMT 25 APRIL 1982 (MSL PRESSURE)

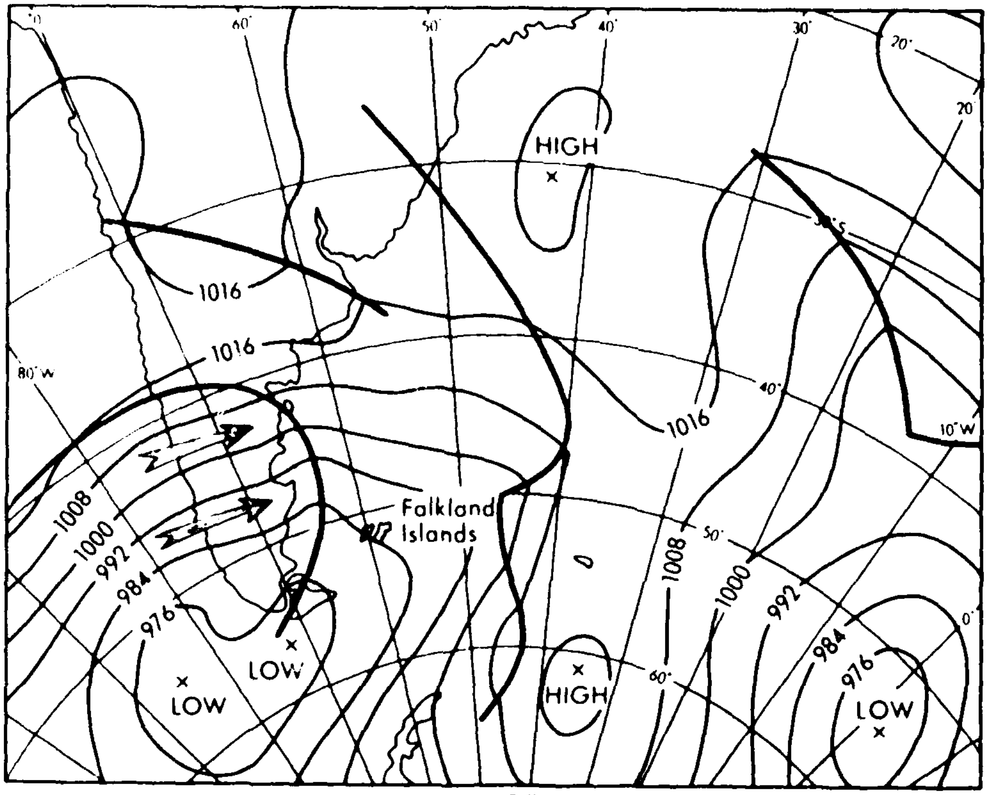


FIGURE 5

1200 GMT 7 JUNE 1982 MSL PRESSURE (MB)

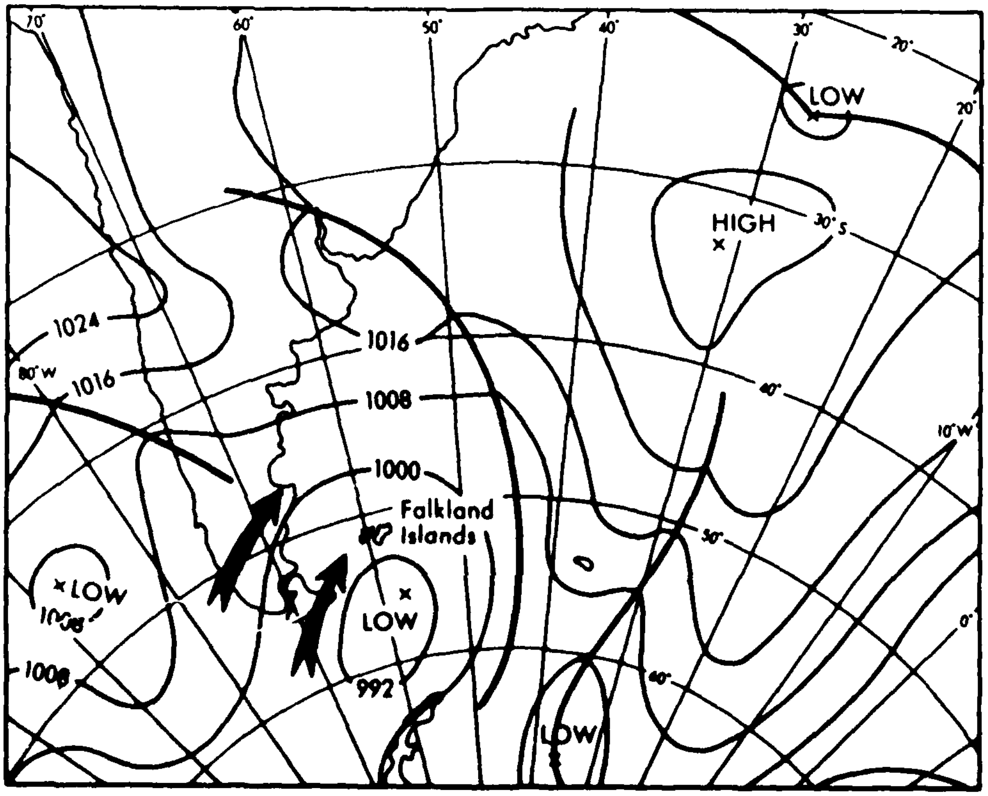


FIGURE 6

1800 GMT 8 JUNE 1982 MSL PRESSURE (MB)

Figure 8 AVHRR-IR NOAA-7 Composite false colour images 1954 GMT 9 JUNE 198[illegible]

DEVELOPMENT OF SATELLITE DATA PRESENTATION
FOR ENVIRONMENTAL FORECASTING

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SUMMARY

This paper describes the techniques developed during and since the operation to recover the Falkland Islands using image processing to enhance the value of meteorological satellite images for environmental forecasting. Data were used from METEOSAT, GOES-E and NOAA 7 AVHRR. Among the methods adopted were the production of time-lapse sequences of images and multi-temporal colour composites for the analysis of weather system dynamics, multi-spectral colour composites for cloud type identification and radiance temperature measurements used for sea surface temperature measurement, ice detection and fog discrimination. Some of the problems encountered are described and how they were overcome. The image processing system used was a prototype for a Satellite Environmental Data Acquisition System about to enter service with CINCFLEET Weather and Oceanographic Centre.

1 INTRODUCTION

During Operation Corporate to recover the Falkland Islands, the primary sources of data for oceanographic and meteorological forecasting in the South Atlantic were meteorological satellites. This paper describes the ways that data were received and presented for analysis. The paper by Marsh and Pothecary[1] describes the subsequent applications. Before the period in question, the Royal Aircraft Establishment (RAE) was already working on advanced techniques of image analysis and display. It also operated a meteorological satellite receiving station, RAE Lasham in Hampshire, for which the UK Meteorological Office was the primary user. The association of these two aspects of the work of the Remote Sensing Division of Space and New Concepts Department had already led to the formulation of a Royal Navy requirement for an image processing system for operational use at CINCFLEET Weather and Oceanographic Centre to be linked directly to Lasham. This system is the Satellite Environmental Data Acquisition System (SEDAS). The accelerated development and operational use of the prototype system during Operation Corporate confirmed the integrity of the concept and provided an invaluable interchange of ideas, requirements and experience.

This paper describes only techniques to aid the analysis of images from satellites. These images are formed by detecting reflected visible and near-infrared sunlight and thermally emitted infrared radiation. Current meteorological satellites also carry other sensors of undoubted worth, but their analysis, processing or use are outside the context of this paper.

2 SOURCES OF DATA

RAE Lasham routinely receives data from three satellite systems. These are the polar orbiting NOAA series and the geostationary METEOSAT operated by the European Space Agency (ESA) and GOES-E operated by the US National Oceanic and Atmospheric Administration (NOAA)[2]. These are also the three systems used over the South Atlantic. The shift in geographical emphasis from normal operations in the northern hemisphere posed no problems with regard to reception of the geostationary satellites, since they view an unchanging near-hemisphere of the Earth, all of which is available to any ground station within their reception zone. Thus Lasham was able to meet the changed needs in their case. This was not so with regard to the polar orbiters. In effect due to problems on board NOAA 6, NOAA 7 was the only useful source of data in this set. Data from the South Atlantic from NOAA 7 could not be received at Lasham since the satellite was not in view of the receiving aerial and no alternative receiving station in the region was available to the UK. The satellite has the capability to record data on board for subsequent replay over a ground station. However the operational needs of the satellite precluded replay over Lasham even had the station been reconfigured and modified to receive the signal.

The most straightforward satellite data to process and display were those from METEOSAT. Two data streams were available at Lasham. Each involved the transmission of the raw satellite data to the European Operations Control Centre at Darmstadt in Germany for processing and subsequent dissemination to user ground stations back through METEOSAT used as a transponder. The secondary data use system (SDUS) stream is an analogue system compatible with weather facsimile (WEFAX) low resolution, low data rate facsimile picture data distribution. For the applications of interest here, primary data user system (PDUS) data were used. This has a higher data rate of 166 kb/s but provides access to all three sensor channels at the best possible spatial resolution. The channels are sensitive to reflected sunlight between 0.4 and 1.1 μm which has a resolution of 2.5 km at nadir, to thermally emitted infrared from 10.5 to 12.5 μm with a spatial resolution of 5 km at nadir and a water vapour emission band extending from

5.7 to 7.1 μm, also with a spatial resolution of 5 km at nadir. METEOSAT scans a near-hemisphere of the Earth once approximately every 30 minutes. The centre of the scene is the equator at 0° longitude.

The sensor on GOES-E has two spectral channels. One extends from 0.55 to 0.7 μm with a spatial resolution of 0.8 km in principle at nadir. The other extends from 10.5 to 12.6 μm with a spatial resolution of 6.4 km at nadir. It takes 18.2 minutes for the sensors to scan one quarter of the Earth's disc. GOES-E is in orbit above 75°W longitude. From Lasham it is visible only 1.3° above the horizon. The long atmospheric reception path restricts data reception to the WEFAX analogue transmission. Before GOES images could be displayed it was necessary for them to be digitised into a computer compatible format. Facilities to do this did not exist in the early stages of the operation. Instead the analogue data were transmitted by telephone line to the Meteorological Office who were able to digitise the data. Another car courier service brought the subsequent tapes to Farnborough.

The NOAA 7 sensor used is the advanced very high resolution radiometer (AVHRR). The spectral bands are: band 1 from 0.58 to 0.68 μm; band 2 from 0.725 to 1.1 μm; band 3 from 3.55 to 3.93 μm; band 4 from 10.3 to 11.3 μm; band 5 from 11.5 to 12.5 μm. The spatial resolution in each case is about 1 km at nadir. The band 3 signal has suffered a progressive deterioration and during Operation Corporate was too noisy to be of better than limited use.

3 THE IMAGE PROCESSING SYSTEM

The image display and processing system used to present the satellite images is called GEMS. This consists of a hardware image handling system, a host computer and the image processing software. The system configuration is shown in figure 1. The GEMS hardware was developed to an RAE specification by Computer Aided Design of Cambridge. It includes an image store which is a 1024 by 1024 element array where each element is an 8 bit number. This array is normally divided into four separate 512 by 512 by 8 bit deep image planes that may be displayed on the video monitor. There are in addition four 512 by 512 by 1 bit deep overlay planes that can be used to present graphics, text or highlights on the image display. The image display is under the immediate control of a PDP-11 computer built in to the hardware. The system is under the control of another mini-computer. During Operation Corporate a system hosted by a Prime 750 was used, but such a powerful machine is not necessary. SEDAS uses a Prime 250 for example. The host computer performs the image processing and controls the transfer of data from tape to the disc units that act as the working store of available images and from the disc into the system for processing and display. Working practices during Operation Corporate required a very large working store and two 300 MB disc drives were used. SEDAS when installed with CINCFLEET will be able to perform with a 96 MB disc drive as the flow of data in and its analysis will be more uniform throughout the day. The GEMS software called Gemstone was written at RAE. It was designed to allow use of the system without detailed knowledge of how it works or any familiarity with computer operation. The computer terminal is used to load the available satellite data from tape to disc and then call up Gemstone. At that point figure 2 appears on the video monitor and control transfers to a simple ergonomically designed control panel. A tracker ball moves the cursor to within a box representing the intended next step which is executed by pressing a single input button. When this is done to select an image, the display changes to a list of the images available on the disc. Following selection of one using the tracker ball again the display changes to that shown in figure 3. The next step is to copy the data into the display store. In all circumstances the cursor defaults to the most likely next step unless over-ridden by the tracker ball and prompts an unfamiliar operator through the options. Figure 3 apparently shows 16 available image stores although only four were ascribed to the GEMS hardware. The 12 making up the difference are virtual stores within the host computer. They may be used to store images and processing can be performed on data in them in the same way as on data in the other four. However, they must be copied into one of the four GEMS hardware stores before they can be displayed. The display is restricted to 512 by 512 picture elements or pixels. Most images are much larger. Therefore when first selected a subset of the full data set is copied into the display store sampled by pixel and by line automatically to show the full scene on the screen. Processing can be carried out on the full scene or sub-scenes may be selected for closer examination at higher resolution. Processing options are selected by the same method of using the tracker ball to identify procedures in a prompted system of pages of menus. The selection of which colour gun or guns of the monitor display which store is done arbitrarily from the control panel. Similarly the colour or deletion of the overlay planes can be chosen at will. The display can be magnified by up to 8 times from the control panel by pixel replication. When magnified in this way the full size of the video screen, about 900 by 600 pixels, is used. The results on the screen can be preserved by dumping the scene onto the system disc, by recording the scene on polaroid colour film using a Honeywell device which incorporates its own enclosed video monitor, thereby ensuring consistent results and removing the need for a camera to photograph the screen, or on a video recorder.

GEMS is a general purpose image processor. This paper describes work using meteorological satellite images for specific applications as required during Corporate and for SEDAS. Nevertheless any image data presented in a compatible format may be analysed. GEMS is used routinely at RAE for Landsat and synthetic aperture radar work.

4 PRESENTATION TECHNIQUES

4.1 METEOSAT

METEOSAT scenes were readily available and comparatively easy to handle because the necessary special software was already well under development at the start of the conflict. Unfortunately the Falkland Islands lie on the western-most extremity of the area of coverage and as the weather development came from the west the usefulness of this source was limited. However it was still widely used and had particular application in the earliest phase of the operation en route to Ascension Island and when the links to acquire LAC data were still being established. As the projection and viewpoint of METEOSAT images does not vary, the superposition of geographical coordinates and coastlines was relatively straightforward. Figure 4 shows a full scene from the thermal infrared channel with the geographical information in the overlay planes. To improve their visibility the overlay planes would normally be coloured. After various experiments blue for the coastline and yellow for the grid was found to be the best combination for visual

inspection and photographic recording. In general the area of interest was less than the full scene. The standard format and constant projection made it possible to automate the selection and extraction of specific areas. Figure 5 shows the standard South Atlantic extract. Automatic and semi-automatic selection of scenes in this way was of immense value when a great deal of data had to be analysed rapidly to meet briefing and forecast preparation deadlines reliably. The data were presented in three different ways. Time lapse sequences of images from the thermal infrared channel were displayed. Although apparently restricted to a maximum of four display planes, in fact the available image planes in GEMS were further subdivided by modifications to the controlling software. By storing several different sub-images in each image plane and controlling the display output only the relevant part of the data in each plane were shown. In that way many more scenes can be made available. By accepting degradation of both spatial resolution and dynamic range, up to 80 scenes can be presented as a sequence. With METEOSAT up to eight scenes were normally used corresponding to intervals of three hours or a daily cycle. These sequences allowed the dynamic behaviour of weather systems to be assessed rapidly. Features could be located using the cursor on the display to identify a point. The latitude and longitude of the point would then appear on the computer terminal visual display unit (VDU). Distance could be measured in the same way to measure the speed at which weather systems were moving. Sequences were recorded on video tape for subsequent demonstration and confirmation of analyses at CINCFLEETWOC but the primary purpose for this technique was for rapid assessment by the duty naval officer on his daily shift at Farnborough. The second method for the display of METEOSAT data was developed as a means of providing a measurement of cloud movement that could be prepared by a meteorologically untrained observer and sent as a hard copy photographic print for analyses. It was little used during Corporate but has aroused interest since. Two successive METEOSAT images are displayed simultaneously on the colour video monitor. One, say the earlier example, used the blue and green guns of the monitor, the later the red gun. Areas where cloud is common to both appear white. Areas which were cloudy on the earlier scene but not later appear blue-green. Areas where cloud has developed during the interval show red. This technique, like the time lapse sequences, uses the thermal infrared data. The third method of presentation combined the visible and infrared channels into a colour composite. By experiment contrast stretches were defined which could be applied to the separate channels with the result that different cloud types and heights appeared as different colour shades. By this technique as in the second case, hard copy information could be and was prepared by non-forecasters and sent by courier to CINCFLEETWOC. Little use was made of the GEMS for display of the METEOSAT water vapour channel.

4.2 GOES

The GOES coverage zone was ideal for examining the weather expected in the South Atlantic. It was frustrating therefore that only low quality facsimile data were available. Nevertheless they proved very valuable. As mentioned in Section 2, the GOES sensor produces separate images corresponding to quarters of the full disc of the Earth. Extracts from the southern hemisphere were taken showing the area of interest in two scales. At first the assembly of these sub-scenes into a mosaic had to be done manually, but later an automated technique was developed. Some monitoring and intervention had to be retained in this procedure as the GOES data were prone to corruption. Geographical overlays were prepared as for METEOSAT. The major problem with GOES scenes was interference from another experiment on board the satellite. This was present for about 16 hours a day. It was manifest as bright lines across the image. Figure 6 shows the standard GOES pair of mosaics with this interference present. A filtering technique was developed whereby a 1 x 3 pixel box was passed over the image. The relative brightness of the pixels in the box was examined in each position. If the values of the extreme pixels exceeded that of the middle pixel by greater than a given threshold, the value of the middle pixel was replaced by the mean of the extremities. The threshold level could be selected by the operator but a standard default value of 21 grey scale levels was found to be adequate. This technique called linefix vastly improved the interpretability of the images. Figure 7 shows the same scene as figure 6 after linefix. Eventually the compilation of the mosaics, the application of linefix and assembly of the results into a time lapse sequence was reduced from a series of separate manual tasks to an automated procedure. Seven images were assembled into a sequence for each day. They represented intervals of 3 hours except that GOES does not transmit data at 0300. As for METEOSAT, the time lapse sequences were recorded on video tape for subsequent further review at CINCFLEETWOC.

4.3 NOAA AVHRR

Standardised techniques to deal with METEOSAT and GOES data were generated quite early. The application of AVHRR data however grew throughout Operation Corporate and has continued to grow since. There were two initial uses. The first was to prepare colour composites using bands 1, 2 and 4 for daytime passes or 3, 4 and 5 at night of the full LAC scenes for meteorological analysis. The second was to use bands 3, 4 and 5 for sea surface temperature analysis. Between 2 and 4 scenes were received each day from NOAA 7 of the general area. All were valuable for meteorological analysis. Following visual inspection of all bands by the duty forecaster, the colour composites were produced. These were contrast stretched using a standard transfer function that produced consistent and reproducible results for the distinguishing of cloud types and heights. Photographic hard copies were produced for CINCFLEET, the Meteorological Office and other Ministry of Defence users. Geographical coordinates and coastlines were overlaid on the AVHRR scenes. Figure 8 shows the area covered by a full scene with this information added. Unlike the images from the geostationary satellites, the AVHRR images have a different projection from pass to pass. To transform the image to a standard cartographic projection would be very expensive in terms of computer time and for these applications quite unnecessary. Instead the orbital information and sensor characteristics are stored and then by using the time information included in each AVHRR line of image data to define the start of the scene, used to transform and redraw a stored world map to the particular projection of each image. As the amount of data in the map is very much less than in an image, this transformation takes only a few seconds. The intervals in the geographical grid may be selected by the operator as appropriate for the area under analysis. If four NOAA 7 passes were received for one day, two would usually be of areas to the west of Chile. These were not often of interest for sea surface temperature analysis and this application in general used the other two scenes covering the South Atlantic. Suitable cloud free areas were identified using the full scene. One is marked on figure 8. Data from the infrared channels were read into the image planes. Bands 4 and 5 were always used. Band 3 data are only useful at night as that part of the spectrum is contaminated by reflected sunlight during the day.

less and less use was made of this channel as the noise problem mentioned in Section 2 worsened. However band 3 data were used when possible. First a linear contrast stretch was applied to each band used to remove the cloud and land detail and spread the range of grey scales corresponding to the sea surface temperature variation across the whole dynamic range of the video monitor. After visual inspection of the structure of the variation selected temperature measurements were made at points determined by the forecaster. The temperatures were derived from the radiances measured by the sensor using a standard NOAA algorithm. No correction was made for atmospheric contamination. As the primary aim was to identify variations and discontinuities and to quantify the relative change across thermal boundaries, this correction was not considered to be necessary. Surface observations during the Operation confirmed this assessment. Points at which the temperature was measured were usually identified using the cursor controlled by the tracker ball. An indefinite number of such points could be designated. The latitude and longitude of each point and the temperature appeared in each case on the VDU. In addition the information was dumped to a file opened each time this mode of operation was selected. When required the contents of the file were written by line printer to provide hard copy free from transcription errors. Variations available in the temperature measuring mode allowed the latitude and longitude of the desired point to be designated, or the two ends of a line could be defined using the cursor and the temperature along the line plotted and displayed on the VDU. Traces corresponding to each of the three thermal infrared bands could be displayed simultaneously. This technique was of particular use where band 3 data were available as variations between the bands allowed the degree of atmospheric water vapour contamination to be assessed. Figure 9 shows a contrast stretched single band with a line marked and the temperature profile along it shown.

The above two uses were those foreseen for the AVHRR from the outset. Other applications developed. The first was the recognition that the images showed ice fields very clearly. Estimating the position of the ice edge became a regular procedure. Colour composites using visible and infrared bands were essential. A single black and white band would not show the ice with any clarity. Composites showed where ice was developing and hence could provide accurate forecasts of where the ice edge would grow. The observation of the ice edge permitted the recovery of South Thule to proceed in mid-June 1982 since the AVHRR images showed the area to be unseasonably free of ice. From observation of the ice field the next development was to attempt to track floating ice. This met with limited success as in general the images received were not sufficiently cloud free. Nevertheless icebergs and bergy bits were identified and their position established. The focus of attention on the AVHRR during Operation Corporate has led to further development. One subsequent example has been the use of the infrared channels to identify fog. On a single band, fog and cloud are virtually indistinguishable and on a normal colour composite fog and low cloud cannot be reliably separated. Where all three infrared bands are available it is possible to distinguish fog from other effects. The technique requires each band to be transformed to radiance temperature. When displayed on the monitor the temperature corresponding to each pixel determines the grey level on the screen if a single band modulates all three colour guns to produce a black and white image. However, each band is used to modulate just one colour gun, for example band 3 may be displayed in red, band 4 in green and band 5 in blue. If the temperatures measured for a given pixel are identical for all three bands, the pixel will appear as a grey shade on the screen. If there is a significant variation in the perceived temperature then the result is a colour cast on the image. The normal method for display relates increasing brightness on the screen to decreasing temperature, or for a single band image black is warm and white is cold. Using this convention and the allocation of bands to colours described above, fog appears as an area of dark red. That indicates that band 3 measures a significantly colder temperature than bands 4 and 5. Clouds however appear grey to white, suggesting that the measured temperatures are the same for all bands. There are subtler variations that indicate areas where fog is beginning or likely to develop. The interpretation is that the band 3 signal, corresponding to the shortest infrared wavelength, must arise from near the surface of the fog or cloud since that wavelength cannot penetrate far through suspended water droplets. The longer wavelengths providing the bands 4 and 5 signal can penetrate significantly further and therefore the measured temperature is integrated over a longer path through the suspension. Clouds have essentially a uniform temperature and therefore this effect produces little variation in the perceived radiance temperatures. Fog on the other hand has typically a colder outer shell determined perhaps by evaporative cooling enclosing a warmer core. Therefore the band 3 signal will represent a colder measurement than bands 4 and 5. The other variations showing areas of developing and imminent fog may be explained by considering the relative effects of water vapour concentrations on the different bands as the atmospheric water vapour content may be expected to show significant anomalies at such a time.

Further uses for AVHRR are under active consideration and experiments have been conducted and are planned at RAE and in collaboration with other organisations to quantify the accuracy of sea surface temperature measurements, to account for atmospheric contamination and to use the images in studies of bioluminescence and thermal pollution of estuaries. These results are not yet ready for presentation but underline the usefulness of this versatile sensor when applied in conjunction with sophisticated, flexible image processing techniques.

5 DATA DISSEMINATION

The rapid transition from an experimental prototype research facility to an operational one caused certain logistical problems. The satellite ground stations at Lasham and Oakhanger are about 13 km (8 miles) apart. Each is about 24 km (15 miles) from Farnborough. CINCFLEET at Northwood is about 56 km (35 miles) and the Meteorological Office at Bracknell about 24 km (15 miles) from Farnborough. While insignificant in comparison with some of the problems faced during Operation Corporate, the transfer of data mainly by courier against unyielding timescales was a major cause for concern throughout. As well as the analysis using GEMS, GOES and METEOSAT images were transmitted in near real-time from Lasham to CINCFLEETWOC over telephone lines for image production by Laserfax. This was a considerable improvement on the WEFAX products otherwise available.

The data dissemination for SEDAS will be simplified when the system is installed at CINCFLEETWOC since there will be no need for naval staff to travel to Farnborough. Data will be transferred from Lasham by tape to tape transfer using a system under development at RAE called METSATNET which will use British Telecom Megastream data links operating at up to 1 Mb/s. METSATNET will include links with the Meteorological Office and Bracknell and is intended to be the backbone of a satellite data distribution

system to meet operational and experimental requirements beyond those related to meteorological satellites. In particular the switched message high data rate techniques under development will have particular application to the European Space Agency ERS-1 synthetic aperture radar equipped satellite for which a number of pre-operational demonstrations are envisaged.

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ACKNOWLEDGEMENTS

The support provided by RAE to the Royal Navy succeeded as a consequence of the wholehearted cooperation of many people in the USA, notably in the USAF and NOAA. In addition the operation and development of the equipment was ably assisted by the enthusiastic help of employees of Spembly Ltd who operate the Lasham ground station and provide other support under contract to RAE.

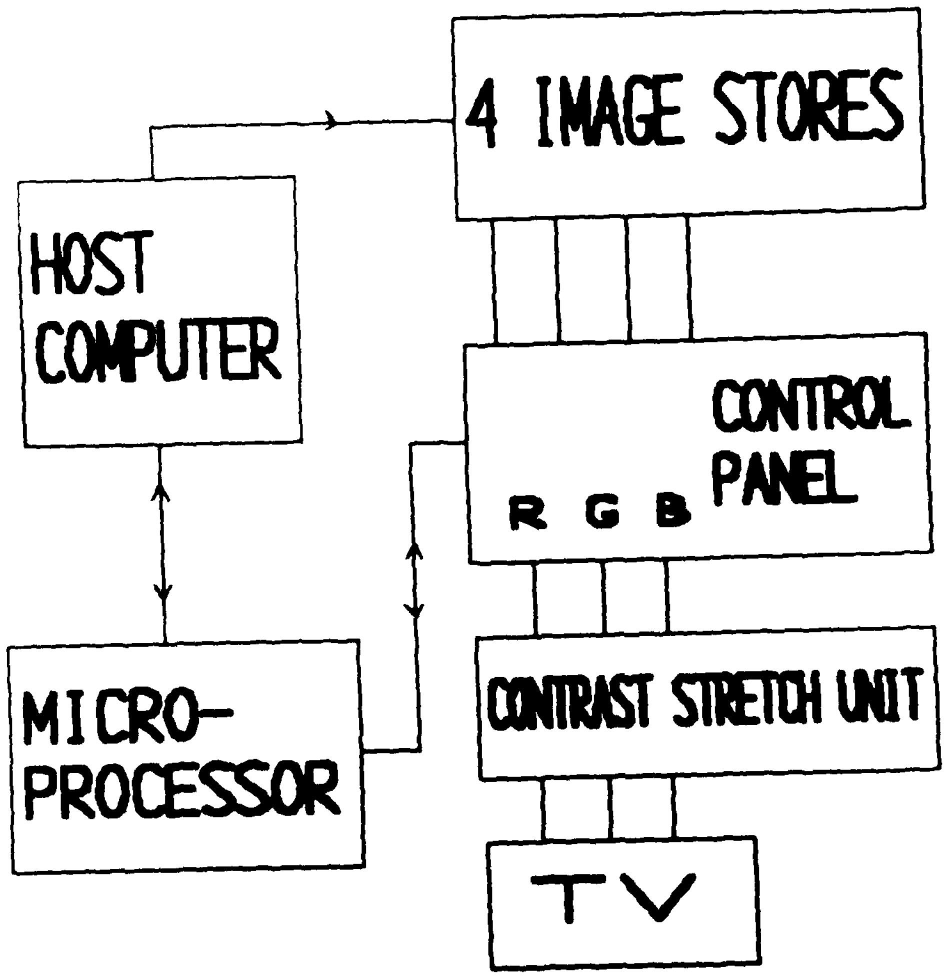

Figure 1 GEMS system diagram.

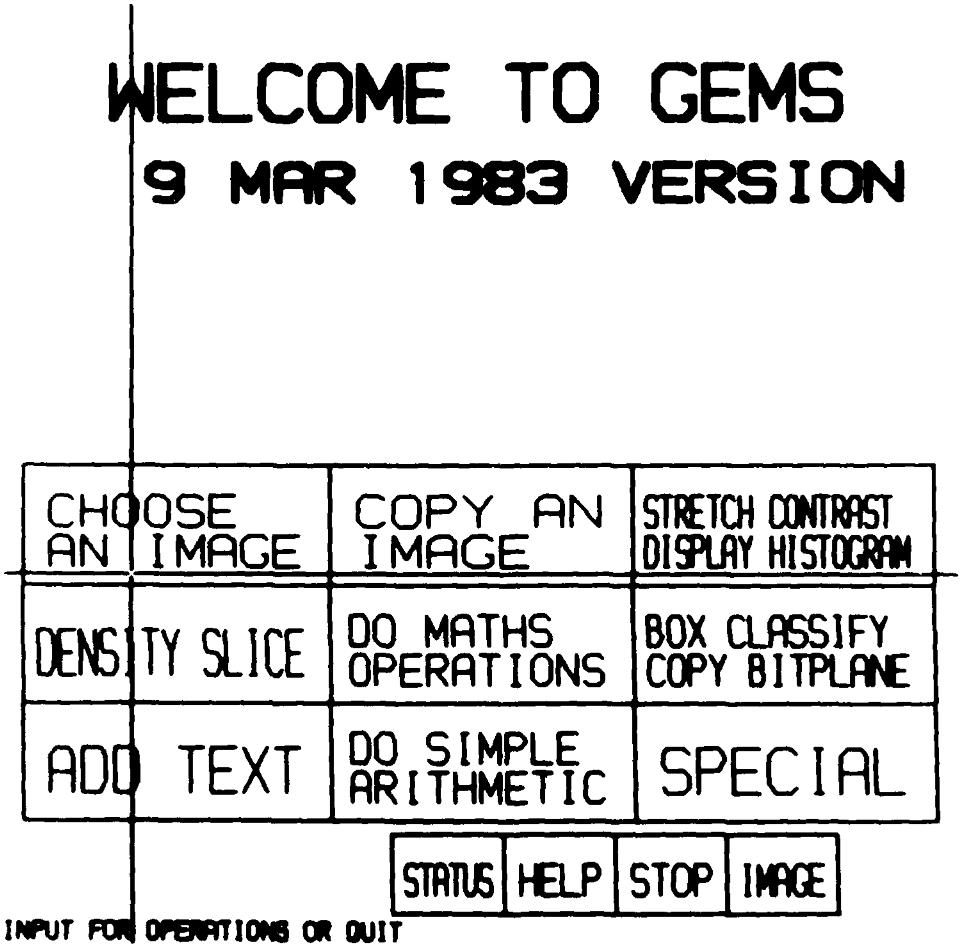

Figure 2 First page of interactive Gemstone display.

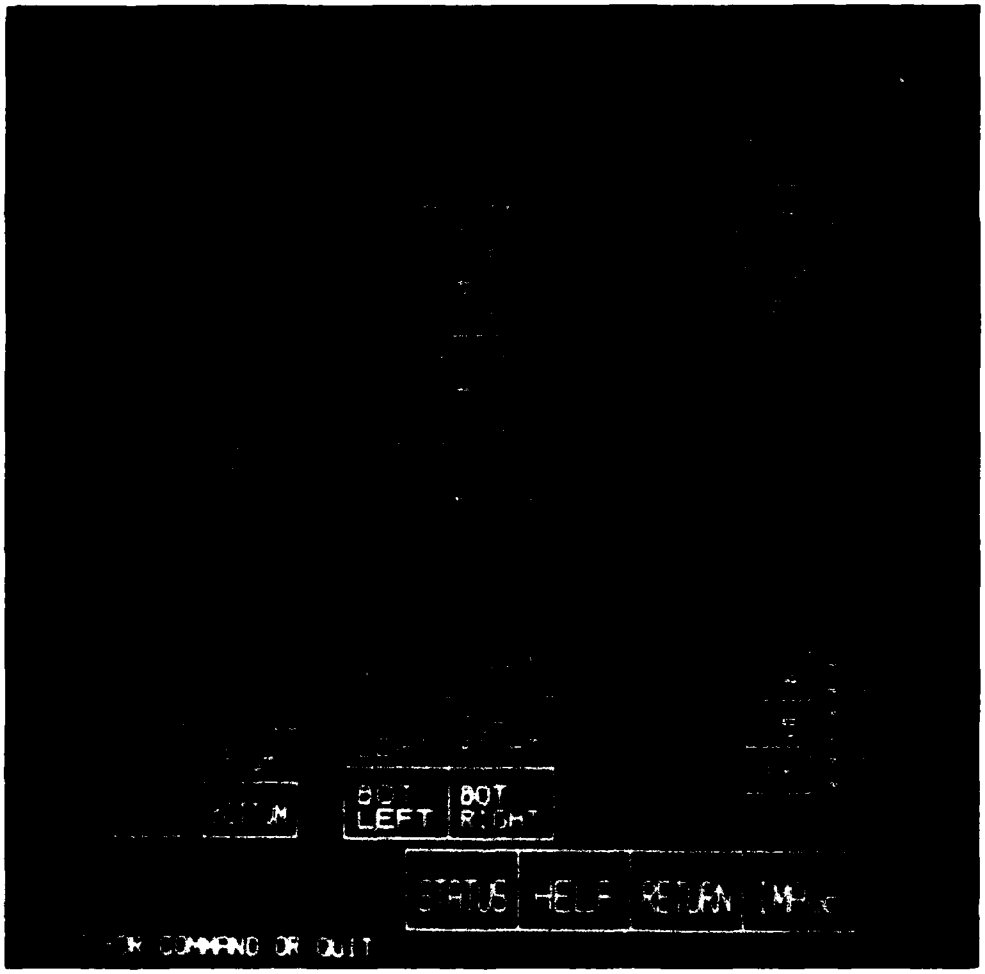

Figure 3 Image transfer and display options.

Figure 4 METEOSAT full scene with overlays.

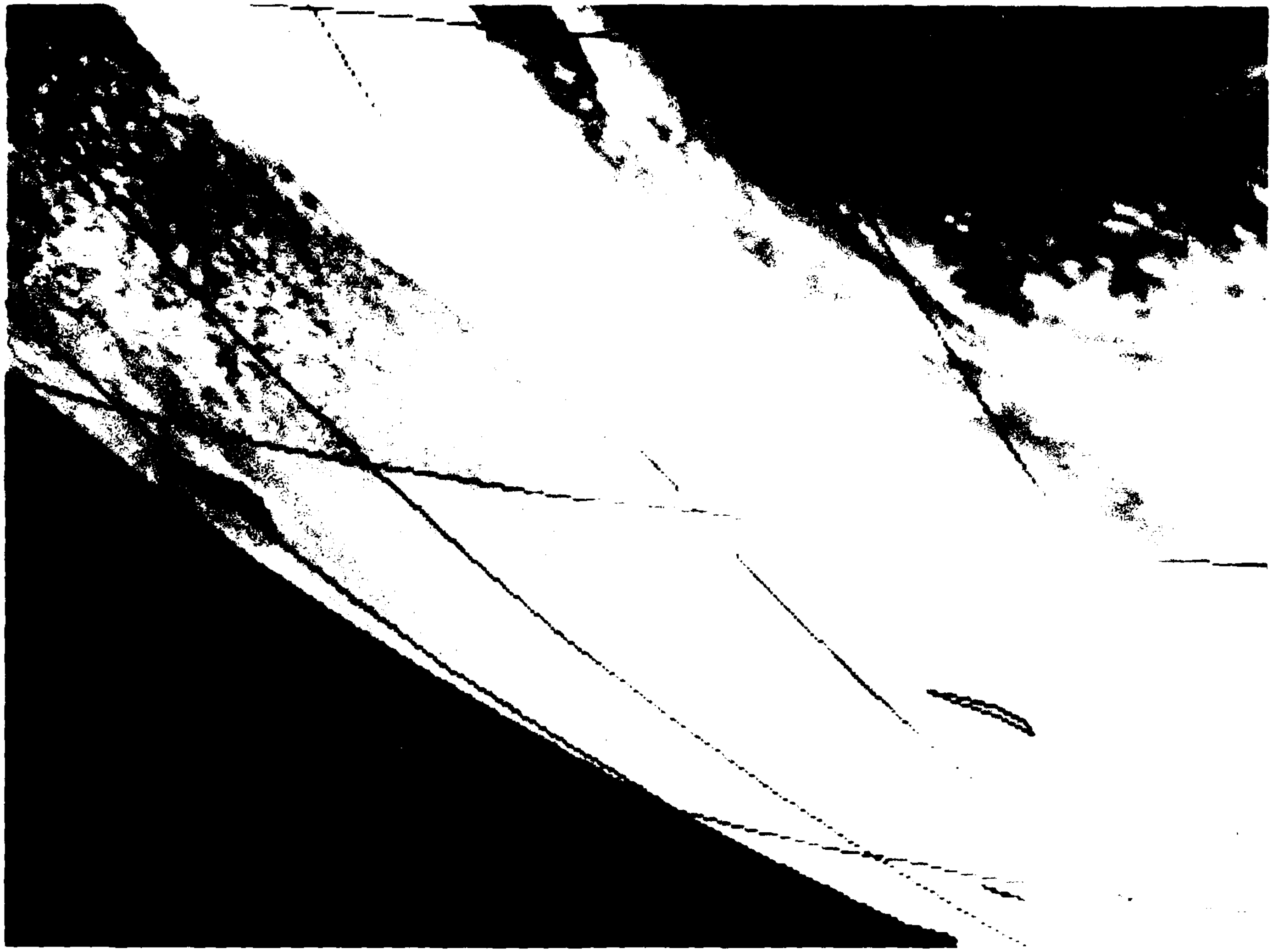

Figure 5 METEOSAT South Atlantic scene with overlays.

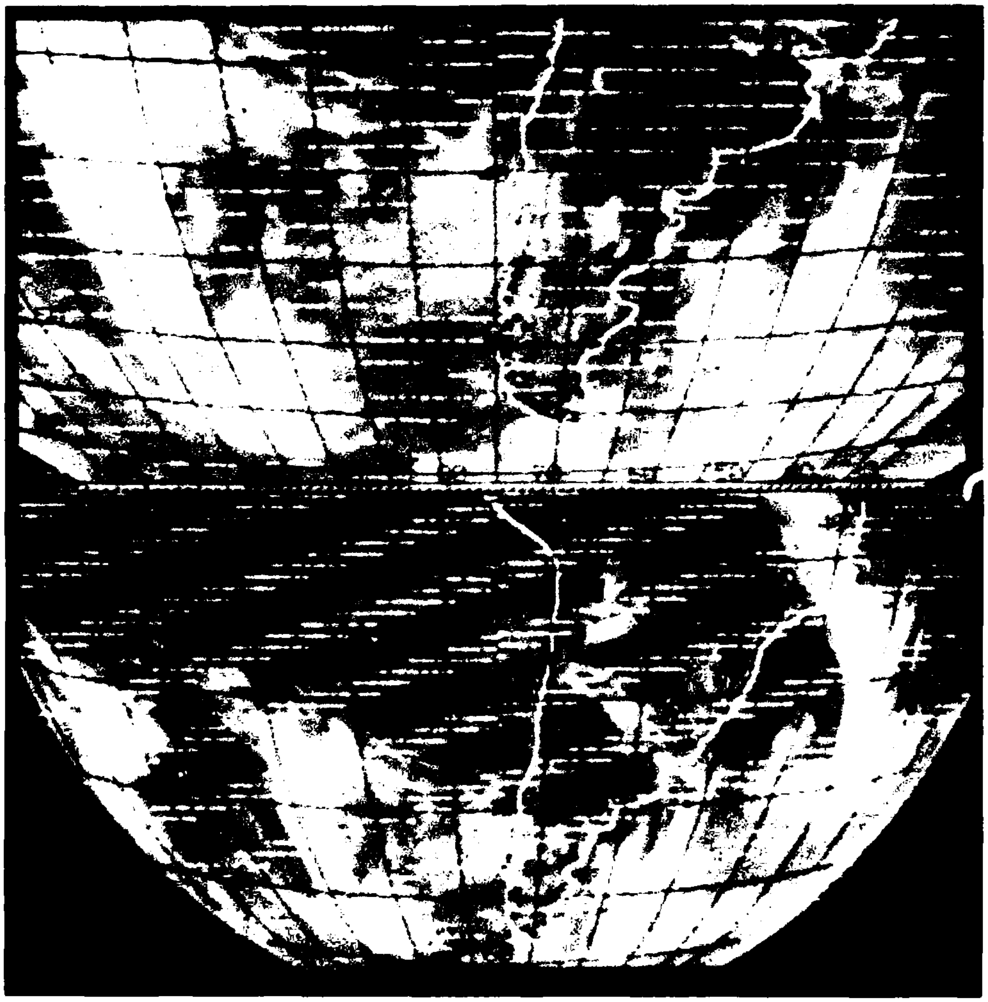

Figure 6 GOES southern hemisphere mosaics at full and half resolution with interference.

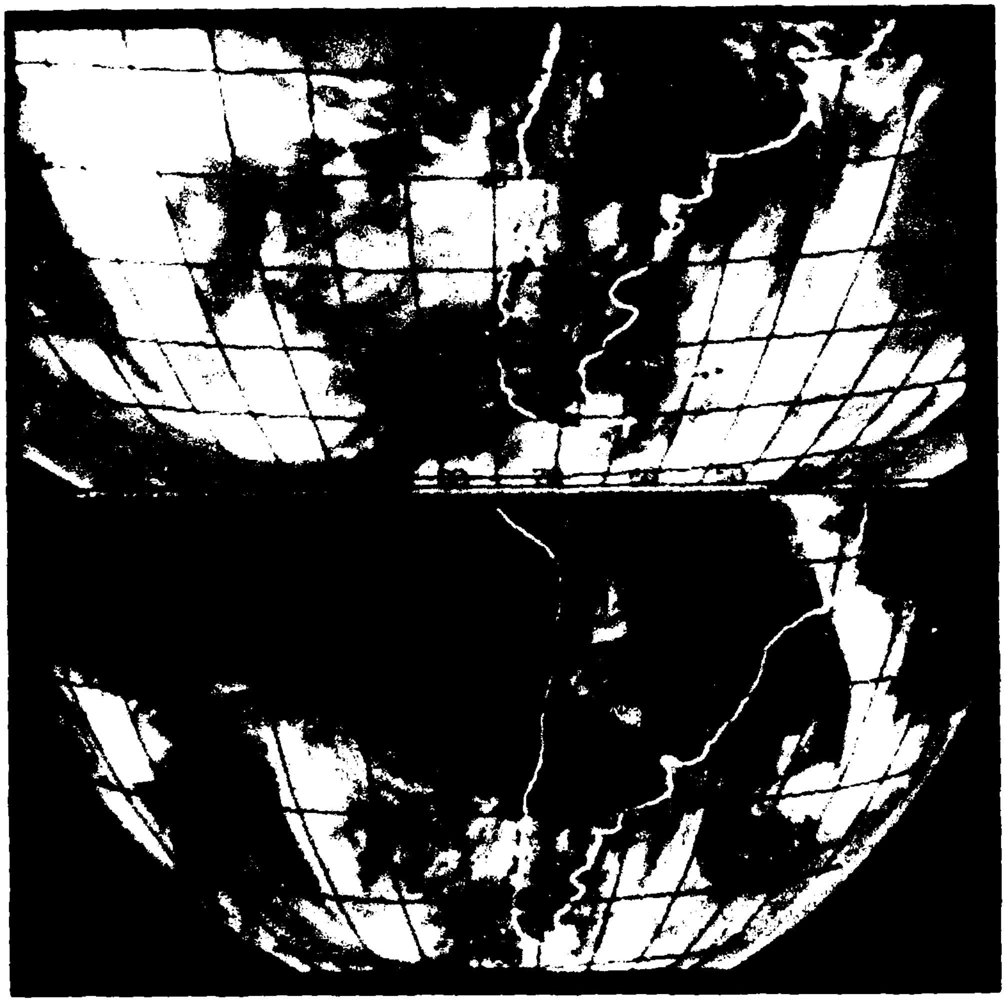

Figure 7   GOES southern hemisphere mosaics at full and half resolution with overlays after linefix.

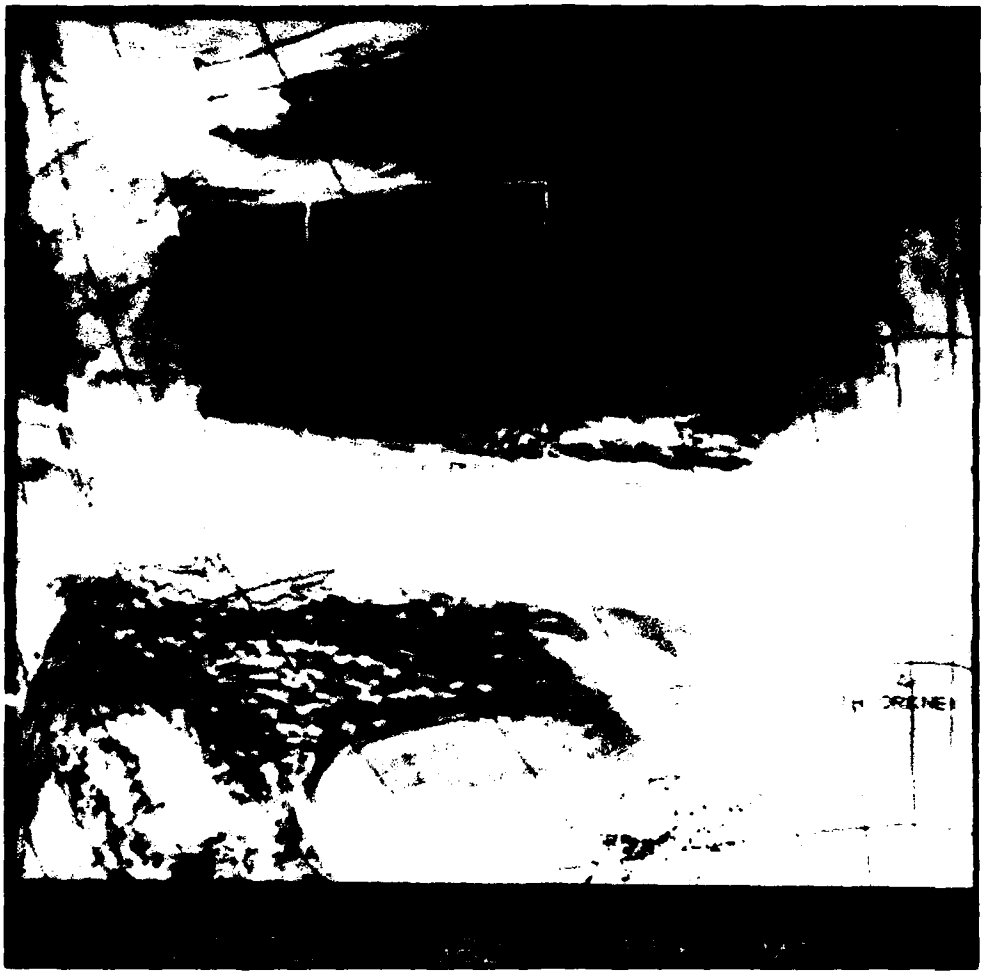

Figure 8   AVHRR band 4 full scene.

Figure 9 AVHRR band 4 contrast stretched for sea surface temperature analysis.

PRACTICAL APPLICATIONS OF SATELLITE-DERIVED METEOROLOGICAL AND OCEANOGRAPHIC DATA IN NAVAL OPERATIONS

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Environmental data derived from satellites give the military commander critical information upon which to base decisions. Since the air-ocean environment can significantly alter the performance of today's technologically-advanced weapons and sensors, the military commander must have access to all factors affecting them. The Satellite-data Processing And Display System (SPADS) at the Naval Eastern Oceanography Center in Norfolk, Virginia is a computer-based system which produces high quality, real-time satellite imagery and data with which to assess meteorological and oceanographic conditions SPADS allows the tactical analyst to receive imagery in real-time, process and display it and interact with the image to maximize extraction of relevant data. The system is described and the following case examples are discussed which demonstrate the capabilities of such a system and show how satellite imagery can be applied to various operational situations:

- Knowledge about the positions of ocean fronts alerts the commander to potentially degraded acoustic conditions and can increase the employment efficiency of sonar systems
- Locating major ocean currents and related mesoscale features saves time and money while increasing safety of ships routed on major ocean transits
- The ability to locate ocean frontal features and forecast their effect upon meteorological conditions results in timely notification to operating units of actions to avoid, or reduce the effect of, dangerous weather
- Time-series sequences of GOES images over the South Atlantic yielded extremely valuable meteorological information in this data-sparse region during the Falkland's Crisis in the spring of 1982

These examples underscore the value of data from satellite imagery to the military commander and illustrate the requirement that a satellite system must provide timely, high quality information within the commander's area of operations.

Today's military commander must realize and understand the effects that the environment will have on his men, ships, aircraft and weapons, if he is going to maximize his combat effectiveness. While some of these effects may be readily apparent, others may affect him in ways which we are only beginning to understand. Even the commander who can ascertain his meteorological or oceanographic conditions, may often find this information limited to his immediate area of operations. He needs the capability to sample the environment beyond his local area.

A cruise missile is launched and before it is beyond the visual horizon forces may begin to affect it which can significantly change its ballistic trajectory. Winds, worsening weather, building seas and atmospheric ducting of electromagnetic energy can singly or collectively work to alter targeting or sensing capability of the missile. A shipboard commander may be experiencing inclement weather which for a variety of reasons degrades the operational capability of his ship, while a short distance away wind and sea conditions are noticeably better.

Satellite imagery can provide valuable information on meteorological and oceanographic conditions in and near an area of operations.

The Naval Eastern Oceanography Center in Norfolk is one of the many environmental centers within the U.S. Navy tasked with acquiring, analyzing and forecasting oceanographic and meteorological conditions for dissemination to national and NATO military activities. While many activities of the Center are common to other oceanographic or weather stations, Norfolk has had the rather unique opportunity during the past two years to evaluate, and then employ in operational scenarios, a computer-based satellite analysis system. It is called SPADS which stands for the Satellite-data Processing And Display System. SPADS is a minicomputer-based copmuter system capable of acquiring satellite data, processing that data into a satellite image displaying that image on a cathode ray tube, and allowing an analyst to interact with the image to maximize data extraction. All this can be done on a real time basis - in some cases within 30 to 45 minutes from commencement of scene scan by the satellite. At the Naval Eastern Oceanography Center data is presently acquired for the GOES-East geosynchronous satellite and the polar orbiting NOAA 7 and NOAA 8. Both visual and infra-red imagery is available. Figure 1 shows a picture of the system.

The ability to have the analyst interact with a satellite image is a distinct advantage over using a hardcopy output of the image. Computer software programs in SPADS allow the user to perform a wide range of operations on the satellite image. See Figure 2. Foremost among these operations is the capability to do variable enhancements of the image over a wide range of gray shades or to do "false color" enhancements of the image. Through the use of appropriate enhancements the analyst can highlight those features in the image which are of most interest to him, whether they be of oceanographic or meteorological significance.

Although the incoming satellite data is received in the natural earth coordinates plane by which the satellite senses the underlying earth scene, this natural projection can be converted by the computer into either Mercator or Polar stereographic projections for use by the analyst. Concurrently, the image can be navigated and a geographic outline and latitude-longitude grid can be superimposed on the image. Manipulation of the image by SPADS is available much like other stateof-the-art image processing systems. These operations include the ability to magnify a certain portion of the image, access a particular picture element and obtain a brightness or temperature reading, mask out undesired cloud features or allow the operator to interact with the image using a graph pen and tablet.

The graph pen and tablet provide the user with a powerful tool to use with the image. Overlay planes can be reserved and placed over the image and the operator can then draw or place symbols on the image. The overlay planes can be stored and recalled at a later time for further comparison or for adding or deleting information on the overlay planes. These overlay planes also permit the analyst to superimpose oceanographic or meteorological fields on an image to assist in the interpretation of observed features.

Another valuable feature of the system is the capability to copy a series of images and then play back this series in a timed sequence so that shifting or movement of features of interest, most notably clouds, can be seen. This has proven to be of great value to our weather forecasters.

Operationally, SPADS has proven to be an extremely flexible and time-sensitive system for satellite imagery analysis.

Four case examples will be discussed which demonstrate the capabilities of such a system and show how satellite imagery can be applied to various operational situations.

Case 1. Satellite imagery and particularly that imagery sensing in the infra-red spectrum, can be used to identify and accurately locate oceanic fronts. Figure 3 shows an infra-red NOAA 7 image acquired and processed by SPADS. The image has not been enhanced by SPADS and contains the full range of gray shades. Not much can be seen in the image, unless one is familiar with the area, in which case the Chesapeake Bay, the New Jersey coast, Long Island, and Cape Cod can be recognized. The image in figure 4 has been enhanced to highlight oceanographic features. The outline of the East Coast of the United States can be seen much better. Major features associated with a dynamic ocean current such as the Gulf Stream are apparent in this image. The North Wall of the Gulf Stream is seen as a sharp boundary between the cooler Slope Water and the Stream core. The Shelf/Slope front separates the Slope Water from the cold nearshore Shelf Water. Two warm eddies are also apparent in the imagery.

The several strong frontal boundaries analyzed in the image combine to create an extremely complex acoustic environment. Sound propagation near and through such boundaries undergoes a myriad of unpredictable phenomena. Although propagation near or across the front currently can not be accurately predicted since most numerical acoustic models assume a homogenous water mass, it is of vital importance for the naval operator to know that his proximity to areas of strong horizontal temperature gradients - that is, fronts, can drastically affect his sonar performance. He can then best deploy his assets to minimize the effect of the front or take into account that acoustic propagation and range prediction may be quite poor

At the Naval Eastern Oceanography Center a major effort is expended in locating the positions of oceanic fronts in the Atlantic Ocean and disseminating this information to operating units. SPADS has played a major role in this effort and will continue to do so as long as the need exists for timely and accurate satellite imagery.

The interactive enhancement of satellite imagery allows the analyst to vary the enhancement curve on an image in order to highlight SST patterns. This is a significant capability. Figure 5 shows the analyzed position of the Gulf Stream from the image in figure 4. Three times a week, or when requested, data on the northern and southern boundaries of the Stream and information on the positions of warm and cold eddies and their size and shape are transmitted via naval message to various ships and support activities. With this data the commander who is attempting to employ a sonar system can ascertain whether the effects of a nearby ocean front will affect his sonar performance, which it probably will even in the case of relatively weak frontal zones, much less a dynamic discontinuity such as the Gulf Stream off the East Coast of the United States. While the physics of sound propagation through frontal boundaries are not well known and only now beginning to receive increasing attention by acousticians, this kind of frontal data can immediately alert a commanding officer to the probability of potentially degraded acoustic conditions which can affect the efficiency of his sonars.

Case 2. The Optimum Track Ship Routing (OTSR) program at the Oceanography Center in Norfolk is an advisory service to military and government vessels which is designed to provide the shortest possible route under the best possible weather conditions during major trans-Atlantic voyages. Intelligent planning of routes before the ships get underway and constant surveillance of possible meteorological and oceanographic conditions which can affect the passage results in fuel savings and less storm damage to ships.

Figure 6 shows the analyzed position of the Gulf Stream based upon observation of a series of images. The chart is thus a composite of where the Gulf Stream's major features have been during the week. Meteorological conditions exert the major influence in most cases where routes are diverted and satellite imagery plays a major role in identifting dangerous weather situations. Additionally, the past several years have seen a dramatic increase in the number of routes which have been planned to take advantage of major ocean currents along the route. A strong, swift ocean current such as the Gulf Stream can give a ship several extra knots of free push on a northbound transit along the east coast of the U.S. or eastbound trans-Atlantic, while ships steaming on opposite courses can avoid these adverse currents. While this is not a new concept, the use of satellite imagery allows the current system to be accurately located and thus for better positioning of the ship to take advantage of or avoid the current. This is important as can be seen in figure 6, when you consider the complexity of the current system.

In 1981 over $500,000 was saved just by shortening the length of voyages. In 1982 routes which used the Gulf Stream saved an estimated $305,000, while avoidance routes saved another $34,000. Combined with over $600,000 in savings due to shortened routes, savings for the year of 1982 was estimated at close to $1,000,000. It is impossible to include in these figures the potentially huge costs of ship repair that might have been required if the ships had not used the ship routing service and had received storm damage.

Another interesting use of satellite data in ship routing is to identify the position of the numerous warm and cold eddies or rings which spawn off current systems and route ships through them to take advantage of their currents. Warm eddies are formed north of the Gulf Stream in the Atlantic Ocean and exhibit a clockwise rotation about its center. Cold eddies form south of the Stream and rotate counterclockwise. Currents in these mesoscale oceanographic features can reach as much as 3 knots. In the spring of 1982 a test was conducted to test the utilization of eddies in ship routing. The results were quite good. In Figure 7 the track of the eastbound ship is seen to cross the northern half of the warm eddies which rotate clockwise. Satellite imagery was able to locate these warm eddies well enough that the ship realized a gain in speed during the transit through the eddies. An estimated $9000 was saved over a distance of 900 nautical miles through the use of the eddies.

Since the test, the Naval Eastern Oceanography Center has actively pursued the use of warm eddies in route planning. As the ability to accurately identify, locate and track these features improves, ships taking advantage of them will surely increase. Emerging technology, such as remote sensors equipped with microwave which will sense these features through the clouds or radar altimeters which can map the geopotential sea surface, will further speed the arrival of the day when ships at sea will routinely utilize eddies to assist them in their transit while decreasing the costs of the voyage.

Case 3. A strong frontal boundary can also influence meteorological conditions. Such is the case along the east coast of the U.S. when a strong cold northwest or northeast air flows out over the Gulf Stream. As the cold air moves out over the Stream there can be a dramatic increase in the turbulence of the air mass. As seen in figure 8, turbulent upward convection over the Stream creates a cold strong downdraft in the vicinity of the frontal boundary. This can result in an increase in winds and seas in the area which can be extremely hazardous to ships or aircraft. This meteorological situation is called the "North Wall Effect". While this can be easily seen off the east coast of the United States, this effect can probably happen anywhere that this type of weather situation occurs. Cloud cover permitting, infra-red satellite imagery provides the capability to identify the position of the North Wall of the Gulf Stream, or any ocean frontal area where this weather condition might occur. SPADS can be used to navigate the satellite data, earth locate the image, and print out points along the frontal boundary as a series of latitude and longitude values. With this information forecasters can provide much more timely message warnings to ships operating in the vicinity of the front.

A graphic example can be given. In April 1982 a naval vessel was transiting westward in the western Atlantic and was being provided with Optimum Track Ship Routing services. The OTSR division at the Oceanography Center in Norfolk recommended that the ship divert from its present course based upon the following developments:

- The ship was located at 37.2N 67.9W and was experiencing winds from 280T at 40 knots. Seas were 8 feet over an existing swell of 33 feet. Sea surface temperature was 22.2C and air temperature was 7.2C.
- Utilizing the satellite imagery on SPADS, it was determined that the ship was in the Gulf Stream in the immediate area of a large amplitude meander (Figure 9). It was also apparent that the ship was experiencing a "North Wall Effect".
- Based upon this knowledge, it was recommended that the ship divert toward a point near 38.5N 69.0W at best speed.
- Later reports from the ship showed that, once she crossed the North Wall and was in colder Slope Water (SST 10.0C, Air Temp 7.2C), winds decreased to 280T at 21 knots. Although the ship did not report sea heights, follow-on messages indicated that seas had improved well enough to allow the ship to increase speed significantly in order to reach port.

Case 4. The use of satellite imagery to assist in forecasting weather conditions in data-sparse regions of the world was seen during the Falkland's Crisis in the Spring of 1982. Using our image processing system, we were able to develop timed sequences of GOES Full Disk images in the South Atlantic. The Full Disk shots were acquired at 3 hour intervals and the magnification

capability of the SPADS was used to "zoom" on the desired portion of the South Atlantic.

The time series produced by the images immediately highlights the general circulation, allows related meteorological features to be associated more easily and gives a better feel for the motion of storm systems and their periodicity. We were surprised by the speed at which vortex centers and related fronts moved through the area - 30 to 40 knot speeds were not unusual. The timed sequences thus proved to be extremely valuable in this region where upper air data and weather maps were not always reliable.

Other uses of satellite imagery to enhance the tactical knowledge of the naval commander become more obvious as the full capability of remote sensing is realized. Additional applications will be developed as the tactical needs of the military are meshed with the emerging capabilities of more advanced satellites. The examples cited in this paper only help to underscore the value of data from satellite imagery to tactical decision making and illustrate the requirement that a satellite system must provide timely, high quality data within the commander's area of interest.

FIGURE 1

SPADS Equipment

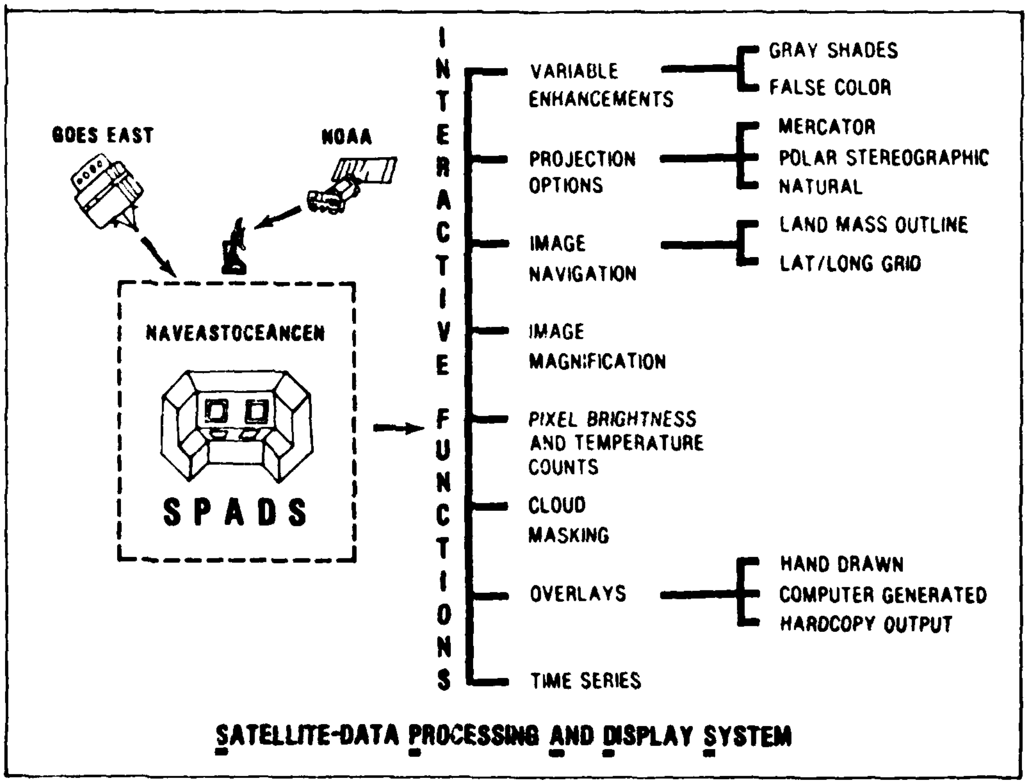

FIGURE 2

Interactive Functions of SPADS

[illegible]

[illegible]

FIGURE [illegible]

Enhanced image with hand-drawn analysis. The analysis would normally be on a red or green overlay. (Inverted image)

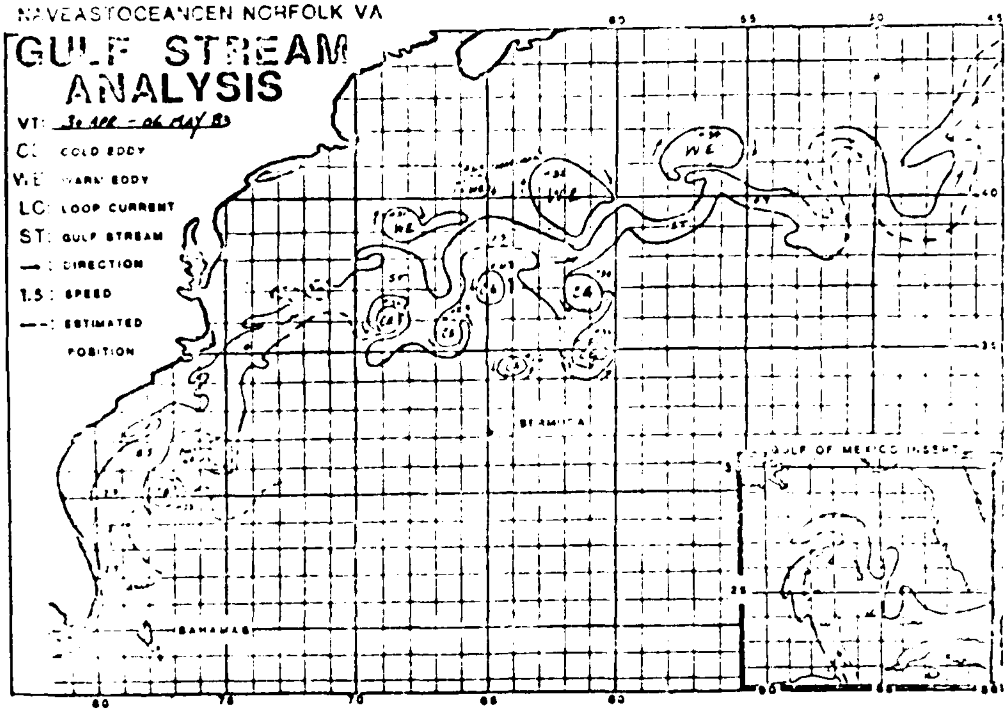

FIGURE 6

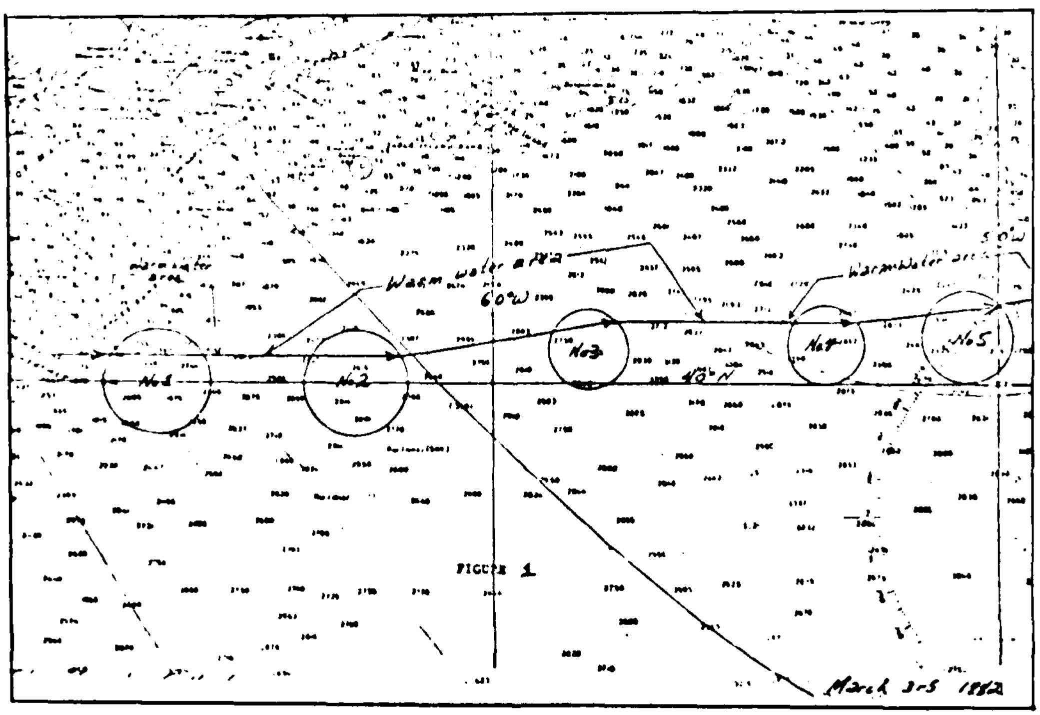

FIGURE 7

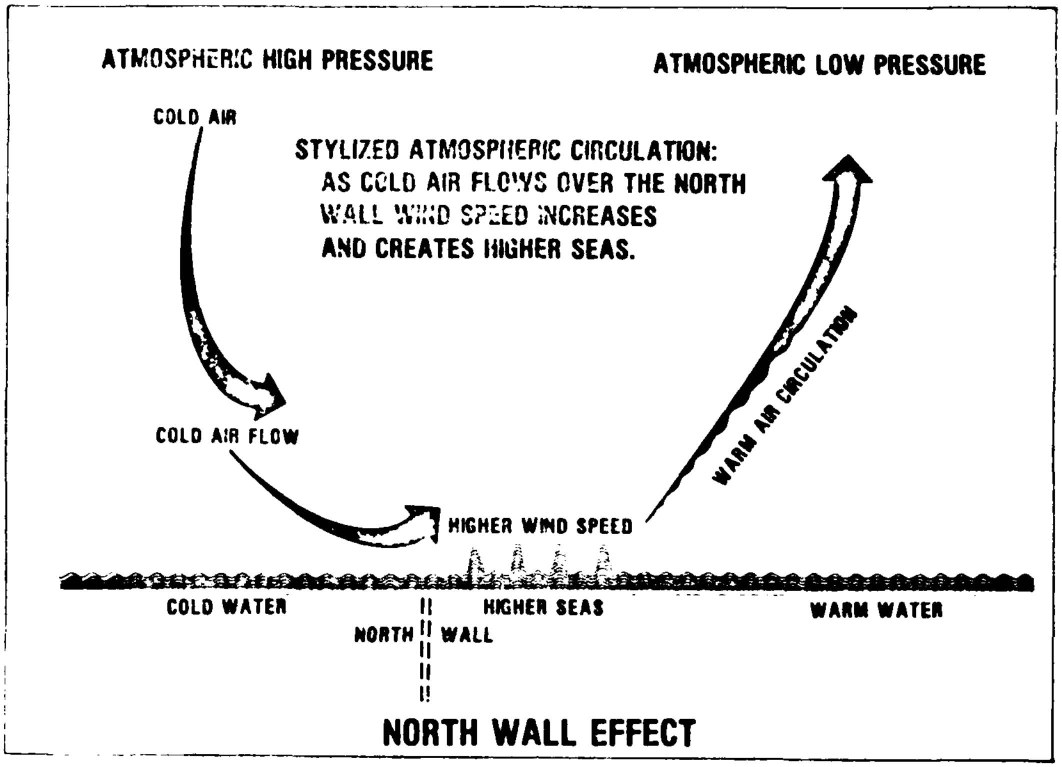

FIGURE 8

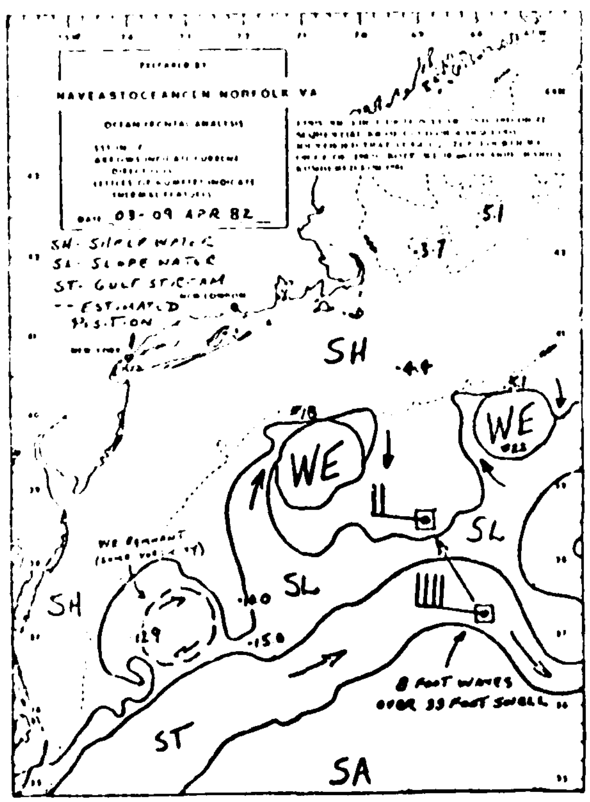

FIGURE 9

STATUS OF THE NATIONAL SPACE TRANSPORTATION SYSTEM

by

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ABSTRACT

The National Space Transportation System is a National Resource serving the government, Department of Defense and commercial needs of the USA and others. Four orbital flight tests were completed July 4, 1982, and the first Operational Flight (STS-5) which placed two commercial communications into orbit was conducted November 11, 1982. February 1983 marked the first flight of the newest orbiter, Challenger. Planned firsts in 1983 include: use of higher performance main engines and solid rocket boosters, around-the-clock crew operations, a night landing, extra-vehicular activity, a dedicated DOD mission, and the first flight of a woman crew member. By the end of 1983, five commercial payloads and two tracking and data relay satellites will have been deployed and thirty-seven crew members will have made flights aboard the Space Shuttle.

The discussion which followed this presentation appears in classified publication CP344 (Supplement)

SHUTTLE/CENTAUR UPPER STAGE CAPABILITY

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SUMMARY

In November 1982, the United States Air Force and NASA signed an agreement which defines a joint project to design, develop, procure, and produce Centaur upper stages for use with the Space Shuttle. A common Centaur G stage 6 meters (19.5 feet) in length is being jointly developed. A longer version designated Centaur G Prime is being developed by NASA to accomplish the Galileo and ISPM flights in 1986. The Centaur G and G Prime will have the capability to place, respectively, approximately 4540 kilograms (10,000 pounds) and 5910 kilograms (13,000 pounds) into geosynchronous orbit from a standard Shuttle parking orbit of 278 kilometers (150 nautical miles) and Shuttle performance (lift) capability of 29,500 kilograms (65,000 pounds).

The advent of high energy upper stage capability in 1986 will permit space users and spacecraft developers to utilize spacecraft growth, stage combination concepts with storable modules, teleoperator systems, and other mission peculiar devices to satisfy complex mission demands. These capabilities should greatly enhance the usefulness of the space environment and stimulate mission planners toward conception of innovative means to meet ever increasing mission requirements.

BACKGROUND

The Space Transportation System (STS), as developed over the past decade by the United States, is made up of several major elements. The Space Shuttle is the key element and provides transportation for payloads from Earth to low Earth orbits. Upper stages are required for missions which require higher altitude orbits, interplanetary trajectories, or for other orbital maneuvers which require higher energy than the Shuttle alone is capable of attaining. Several upper stage programs are in varying degrees of development and operational status at this time. The capabilities of these upper stages range from approximately 1250 kilograms (2750 pounds) for the PAM-D, (a solid propellant vehicle) into a geosynchronous transfer orbit (approximately 630 kilograms or 1400 pounds to geosynchronous orbit), up to the Shuttle/Centaur (a cryogenic stage), which can place as much as 5910 kilograms (13,000 pounds) directly into a geosynchronous orbit from the nominal Shuttle parking orbit.

The requirements for higher energy upper stages were thoroughly examined by NASA in conjunction with the Department of Defense. The results of these analyses were documented in "Upper Stage Alternatives for the Shuttle Era," a NASA/DOD Report to Congress, October 1981, Reference 1. Although many complex mission requirements were examined, the area of spacecraft growth, i.e., physical size versus other ways of meeting increasing mission demands, received considerable thought and discussion during the referenced analyses. Trade studies were made such as comparing the development of costly, complex avionics systems for placement accuracy and maneuverability versus sizing of spacecraft propellant tanks and multiple burn capability. The results indicated the trend to larger spacecraft in the future in order to decrease cost, extend life, provide maneuverability and expand other services. The capability to support these future requirements could only be accomplished through development of a high energy upper stage with inherent flexibility in tank sizing, multiple burn capability, and eventual low thrust options.

In July 1982, the United States Congress passed, and the President signed, a 1982 Urgent Supplemental Bill containing, among other amendments, a stipulation that NASA design and procure the Centaur, a modification of an existing cryogenic expendable launch vehicle, for accomplishing the Galileo and ISPM interplanetary missions in 1986. Upon the reinitiation of the program, the DOD completed additional evaluation of upper stage requirements, which resulted in the requirement for a short wide-body Centaur capability by 1987.

In November 1982, the United States Air Force and NASA approved the Centaur G Subagreement to the NASA/DOD Memorandum of Understanding on Management and Operations of the Space Transportation System, which defines a joint project to design, develop, procure and produce Centaur upper stages. A common Centaur G vehicle 6 meters (19.5 feet) long is being developed. A longer version, an 8.9 meters (29.1 feet) long stage designated Centaur G Prime is being developed by NASA to accomplish the Galileo and ISPM flights in May 1986.

TECHNICAL DESCRIPTION

The Shuttle Centaur G and G Prime vehicles are derivatives of the existing Centaur stage as used with the Atlas/Centaur (A/C) vehicle and the Titan/Centaur launch vehicles. The basic Centaur vehicle has been successfully flown for the past 20 years with

exceptional demonstrated reliability for a variety of missions including commercial, planetary and defense oriented flights. To insure inherent reliability in the Shuttle Centaur configuration, the groundrules and design goals established center around minimum modifications, i.e., those required for compatibility with the Space Transportation System (STS) and for safety considerations in a manned environment. Other considerations were to minimize interfaces with the Shuttle elements for ease of integration and that the Centaur would be an expendable stage. Although reusability has been discussed, such considerations would not be considered until the Shuttle Centaur configuration is operational, i.e., 1986 for Centaur G Prime and 1987 for Centaur G configurations.

The basic A/C configuration and growth progression to the Shuttle Centaur configurations are shown in Figure I.

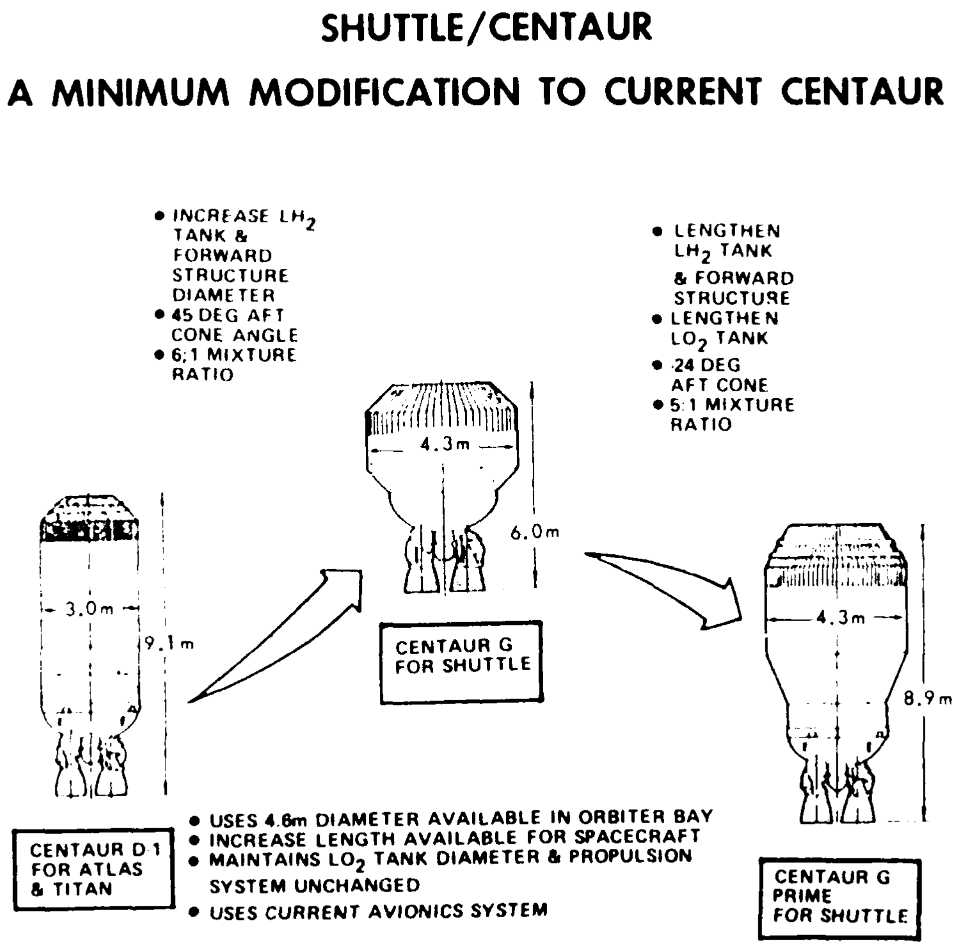

Figure 1

Both the A/C and the new Shuttle/Centaur utilize two RL-10 liquid hydrogen/liquid oxygen engines. These RL-10 engines, produced by Pratt and Whitney, have been flown with 100 percent success. The engines used for the common G vehicle will utilize a mixture ratio of 6:1 (oxidizer over fuel), which results in a thrust level of 66,700 newtons (15,000 pounds force) from each engine, at a specific impulse (I_{sp}) of 440 seconds. The Centaur G Prime, because of tank configuration and performance requirements will use the engines operating at the more efficient 5:1 mixture ratio, providing 73,400 newtons (16,500 pounds force) of thrust each at an I_{sp} of 446.

The liquid oxygen tank for the Centaur G configuration remains essentially the same as the current Centaur. For the G Prime vehicle, cylindrical sections are added to the oxygen tank to provide for the required increase in capacity, i.e., from 11,600 kilograms (25,500 pounds) for G, to 17,500 kilograms (38,500 pounds).

As can be seen in Figure 1, the major modifications are in the hydrogen tank structure. The A/C holds 2400 kilograms (5300 pounds) of liquid hydrogen while the G and G Prime tanks can respectively hold 2050 kilograms (4500 pounds) and 3640 kilograms (7900 pounds) of fuel. The same proven technology and techniques as used in manufacturing

and fabrication of the hydrogen tanks for the current Centaur will be used for the Shuttle/Centaur configurations. The capability to vary tank sizes and/or to offload propellants provides considerable flexibility for future mission requirements.

The basic avionics packages as currently flown will remain essentially the same. However, minor modifications are being made for compatibility with the Space Transportation System and unique mission requirements. The guidance system, used for the current Centaur and both Shuttle/Centaur configurations, is a Minneapolis Honeywell inertial reference system and a Teledyne computer to provide steering commands to the RL-10 engines. Additional avionics have been added to provide two-failure tolerant safing of the vehicle while in the Shuttle Orbiter's cargo bay.

The RF system contains an S-band transmitter, power amplifier, and a hemispherical deployable antenna system. If required, encryptors can be added to provide secure communications.

An instrumentation and telemetry system, signal conditioning and multiplexing capability exists for monitoring system status and performance while in the cargo bay prior to deployment and stage status after deployment.

Primary electrical power to the Centaur, Centaur Integrated Support Structure (CISS) and spacecraft will be supplied by the orbiter while they are in the cargo bay. Batteries will be used to supply electrical power to the Centaur after separation from the orbiter and as a backup to orbiter power while in the orbiter bay.

A pictorial description of the Shuttle/Centaur and how it physically relates to the Shuttle is shown in Figure II. A Centaur Integrated Support Structure (CISS) is a new developed system which provides the major interfaces, i.e., fluid, mechanical and electrical between the Centaur and the Orbiter. The CISS also serves as the erection device and launch platform for deployment of the Centaur, with its payload, from the Orbiter.

SHUTTLE/CENTAUR SYSTEM SUMMARY

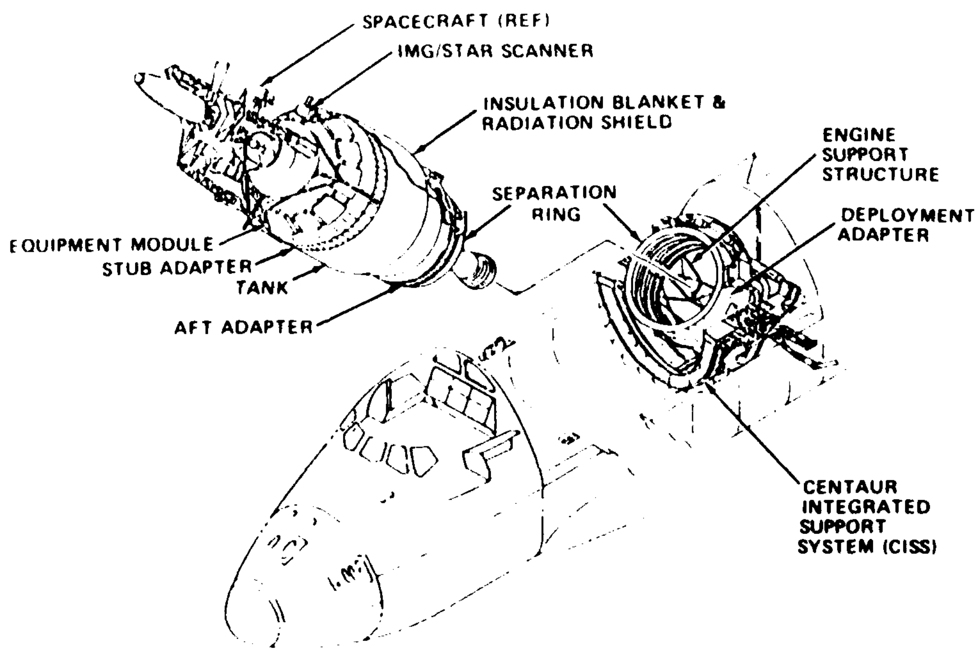

Figure II

The spacecraft is cantilevered from a forward mounting ring on the Centaur stage. Forward supports are an integral part of the Centaur and are utilized for supporting the forward section of the Centaur while in the cargo bay. In low Earth orbit, the Shuttle forward support latches are released and the CISS provides rotation of the entire vehicle to 45 degrees. At the proper time, the separation ring at the aft part of the Centaur is fractured by the use of Lockheed Super-Zip, a proven and currently used system, and 12 springs eject the Centaur from the Orbiter at approximately 0.3 meters per second (1 foot per second).

The capability does exist for the Centaur and payload to be restowed into the cargo bay, should problems occur with the payloads during pre-deployment checkout or should mission requirements change. The total system, as designed, will permit return of the Centaur and payload to a Shuttle landing site should it be desirable to terminate the mission. If this is required while the Shuttle is in orbit, the Centaur tanks would be dumped through ducts provided for this purpose, prior to Shuttle reentry. Similar dumping procedures would also be used should an abort occur at any time during the Shuttle operational phase of the mission.

Two Orbiters are currently being modified for compatibility with the Centaur and both launch pads at the Kennedy Space Center will be compatible with Shuttle/Centaur operations.

PERFORMANCE AND MISSION PLANNER OPTIONS

The Centaur G Prime tanks were sized for the planetary missions, the Galileo and the International Solar Polar Mission. Should this stage be used for geosynchronous missions, it could place in orbit approximately 5910 kilograms (13,000 pounds) of useful payload and still be offloaded by 4090 kilograms (9000 pounds) of propellant at Shuttle lift-off. This is based on a Shuttle lift-off payload capability of 29,500 kilograms (65,000 pounds). Should Shuttle lift-off payload capability increase above 29,500 kilograms (65,000 pounds) additional propellants could be loaded into the Centaur for improved performance approaching 8180 kilograms (18,000 pounds) to geosynchronous orbit. This potential performance capability will eventually permit practical missions involving large space structures and/or large multiple payloads to the same or different orbit positions.

The Centaur G configuration was sized for payload length in the cargo bay instead of maximum attainable performance. This configuration will place 4540 kilograms (10,000 pounds) in geosynchronous orbit with payloads as large as 12.2 meters (40 feet) in length. The limitation on payload length is controlled by the length of the cargo bay, i.e., 18.3 meters (60 feet), and the length of the Centaur stage, i.e., 6 meters (19.5 feet). This performance is also based on a Shuttle parking orbit of 278 kilometers (150 nautical miles) at 28° inclination. Performance at other orbits and inclinations can easily be extrapolated; for example, 6360 kilograms (14,000 pounds) can be delivered to a 57° inclination, highly elliptical orbit.

As the stages are cryogenic, boiloff of propellants becomes an important performance factor. To this end a unique thermal insulation concept has been incorporated into the design. The performance curve relative to loiter time in the cargo bay is shown in Figure III for the Centaur G. As the propellant mass is greater with the Centaur G Prime, the rate of performance dropoff is somewhat lower.

It should be noted that loiter time, boiloff considerations and associated flight performance, were a major item of concern during the performance of the analysis in Reference 1. It was recognized during the analysis that two approaches were desirable: Minimize boiloff through use of innovative insulation concepts and for missions which require exceptional flexibility relative to loiter time, to either add a storable propellant upper stage module or to carry more storable propellants in the spacecraft. Since the Centaur is a cryogenic stage, with high energy performance, the latter concepts are very practical. This being the case, a wide variety of new mission concepts relative to flexible deployment times, satellite positioning schemes, and evasive maneuvering can be implemented within this decade.

Relative to storable module concepts, the General Dynamics Corporation, GDC, has designed, as a proprietary development, such a module for use with the Shuttle/Centaur. In addition, NASA has been studying for several years the practicality of a teleoperator maneuvering system vehicle, now called Orbital Maneuverable Vehicle (OMV). This program may be a new start in FY 85. The combination aspects of storable propellant upper stages, maneuverable satellite systems and teleoperator vehicles should be the subject of a future paper with equal emphasis as this discussion on the Shuttle/Centaur.

CENTAUR G

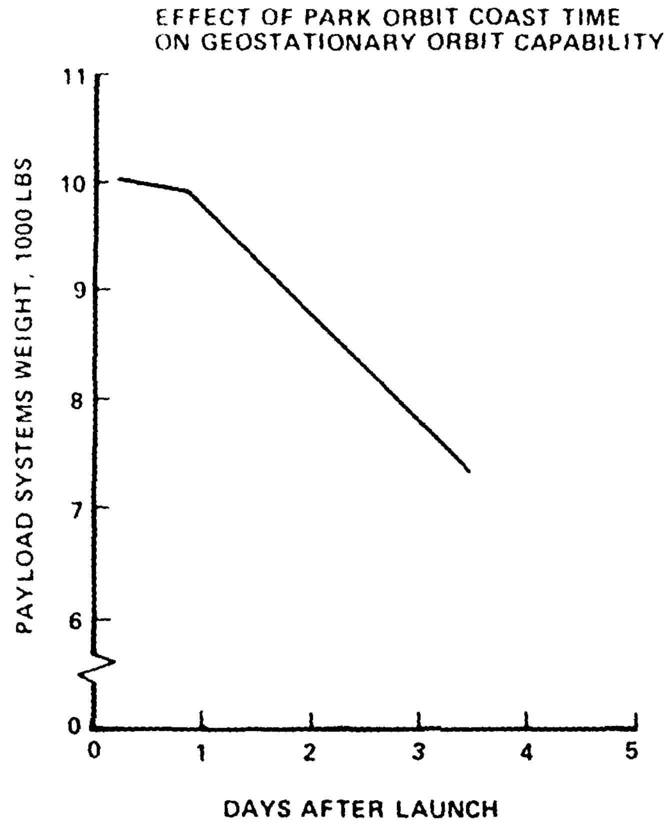

Figure III

In summary, the United States is adding the Centaur, a cryogenic high energy upper stage, as part of the Space Transportation System (STS). This new capability will be in the form of two stage configurations, permitting payloads of 12.2 meters (40 feet) and 9.2 meters (30 feet) in length and respective performance of 4540 kilograms (10,000 pounds) and 5910 kilograms (13,000 pounds) to a geosynchronous orbit. This capability will exist beginning in 1986 and be fully operational in 1987. This added high energy capability opens the door for innovative approaches to meeting increasing mission demands and further utilization of the space environment and its specific advantages for tactical operations.

LA FAMILLE ARIANE

par

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RESUME

Le programme de développement du lanceur ARIANE vient de s'achever avec la réussite des deux tirs de qualification. Il permet de disposer d'un lanceur opérationnel capable de placer des charges utiles de l'ordre de 1800 kg en orbite de transfert de type géostationnaire. Deux phases de développement complémentaires ont été décidées afin d'optimiser le lanceur en fonction de l'évolution des charges utiles, et par conséquent d'accroitre sa compétitivité : la version ARIANE 3 capable d'une charge utile de l'ordre de 2600 kg en orbite de transfert de type géostationnaire et dont la disponibilité est prévue en 1983, la version ARIANE 4, capable de six configurations allant de 2000 à 4300 kg, disponible en fin 1985. Parallèlement, la crédibilité commerciale des lanceurs ARIANE est renforcée par la réalisation d'un deuxième ensemble de lancement disponible début 1985.

ABSTRACT

The development of the ARIANE launch vehicle has just been completed with the success of two qualification launchs. This program has led to an operational vehicle able to launch payloads of about 1800 kg on transfer to geostationnary orbit. Two complementary development phases have been decided in order to optimize the launch vehicle with respect to the evolution of payloads and thus to increase competitivity : ARIANE 3 model able to launch 2600 kg in transfer is scheduled to begin operations in 1983, the ARIANE 4 six different models for payloads ranging from 2000 kg to 4300 kg that will be available at the end of 1985. In parallel the commercial credibility of ARIANE launch vehicles is being increased by the completion of the second launch pas in Kourou (French Guiana) that will start operations at the beginning of 1985.

ARIANE 1 :

La décision de réaliser le lanceur Ariane 1 dans le cadre de l'Agence Spatiale Européenne fut prise en 1973. Le programme fixait pour objectif essentiel le lancement de charges utiles de 1500 kg en orbite de transfert géostationnaire depuis la base de Kourou dès 1980.

Après sept années de développement, le lanceur Ariane 1 effectuait son premier vol fin 1979 et obtenait sa qualification à l'issue de trois tirs totalement réussis sur quatre à la fin de 1981.

Sa performance en orbite de transfert de type géostationnaire a pu être augmentée progressivement sensiblement au-dessus de 1800 kg grâce aux choix conservatifs effectués en début de programme. Les performances théoriques sur les orbites les plus usuelles sont données en annexe.

A l'issue de sa phase de qualification, le lanceur Ariane 1 se présente comme un lanceur tri-étage de 47,79 m de hauteur totale pesant 210 tonnes au décollage, avec les caractéristiques essentielles suivantes :

Le premier étage pèse 13,32 tonnes à vide et mesure 18,4 m de hauteur pour 3,8 m de diamètre. Il est équipé de quatre moteurs Viking V qui développent une poussée de 245 tonnes au décollage. Sa durée de combustion au vol est de 146 secondes.

Les 147,6 tonnes d'ergols (UDMH et N2O4) sont contenues dans deux réservoirs identiques en acier reliés par une jupe cylindrique. Les quatre moteurs à turbopompe sont fixés symétriquement sur le bâti de poussée et articulés par paires selon deux axes orthogonaux pour assurer le pilotage sur les trois axes. Quatre empennages de 2m2 améliorent la stabilité aérodynamique.

Le premier étage s'autodétruit 30 secondes environ après la séparation 1/2.

Le deuxième étage pèse 3,13 tonnes à vide (sans l'interétage et les fusées largables d'accélération) et mesure 11,6 m de hauteur pour 2,6 m de diamètre. Il est équipé d'un moteur Viking IV qui développe une poussée de 72 tonnes dans le vide pendant 136 secondes de vol. Le moteur est lié au bâti de poussée tronconique par un cardan à deux degrés de liberté pour le pilotage en tangage et lacet, le pilotage en roulis étant assuré par des tuyères auxiliaires alimentées en gaz chauds prélevés sur le générateur de gaz de l'étage. Les deux réservoirs - en alliage d'aluminium à fond intermédiaire commun - sont pressurisés à l'hélium gazeux (3.5 bar) et contiennent 34.1 tonnes d'ergols (UDMH et N2O4). Le deuxième étage s'autodétruit 30 secondes environ après la séparation 2/3.

Avant le décollage, pendant l'attente sur rampe du lanceur, les réservoirs du deuxième étage sont protégés par une housse thermique, ventilée à l'air froid, qui limite l'échange thermique entre les ergols

et l'ambiance extérieure. Cette housse thermique est larguée au décollage du lanceur.

Le troisième étage qui pèse 1,164 tonne à vide et mesure 9,08 m de hauteur pour 2,6 m de diamètre, est le premier étage cryogénique réalisé en Europe. Il est équipé d'un moteur HM7 qui développe une poussée de 6 tonnes dans le vide pendant 545 secondes de vol.

Les deux réservoirs, qui contiennent 8,23 tonnes d'ergols (hydrogène et oxygène liquides) sont en alliage d'aluminium avec un fond commun intermédiaire (à double paroi sous vide). Ils sont revêtus d'une protection thermique externe en Klégecell pour éviter l'échauffement des ergols. Les réservoirs d'hydrogène et d'oxygène sont pressurisés en vol, respectivement à l'hydrogène gazeux et à l'hélium.

Le moteur est lié au bâti de poussée tronconique par l'intermédiaire d'un cardan permettant le pilotage en tangage et lacet. Des tuyères auxiliaires éjectant de l'hydrogène gazeux assurent le pilotage en roulis.

Les séparations des étages sont effectuées par cordeaux découpeurs pyrotechniques situés sur la jupe arrière des deuxième et troisième étages. Les étages sont écartés l'un de l'autre par des rétrofusées placées sur l'étage inférieur et par des fusées d'accélération disposées sur l'étage supérieur. La séparation entre les deux premiers étages est commandée par le calculateur de bord sur détection de la queue de poussée du L140 (épuisement d'un ergol). La séparation entre le 2ème et le 3ème étage est commandée par le calculateur de bord quand l'augmentation de vitesse due à la poussée du L33 a atteint une valeur prédéterminée.

La case d'équipements pèse 316 kg ; elle mesure 2,6 m de diamètre et 1,15 m de hauteur. Placée au-dessus du troisième étage, elle renferme les équipements électroniques du lanceur, supporte la charge utile et sert de point d'attache à la coiffe. Dans la case, sont rassemblés autour d'un calculateur embarqué tous les équipements électriques nécessaires à l'exécution de la mission du lanceur : séquentiel, guidage, pilotage, localisation, destruction, télémesure. Seuls les organes de puissance et d'exécution sont répartis dans les étages.

Les deux demi-coiffes sont éjectées parallèlement à l'axe principal du lanceur, sur ordre délivré par le calculateur embarqué lorsque le flux thermique calculé devient inférieur au flux spécifié.

A l'issue de sa phase de qualification, un premier lot de six lanceurs a été commandé par l'Agence Spatiale Européenne. Le premier lancement L5 s'est soldé par un échec dû à la défaillance de la turbopompe du 3ème étage. Le lancement L6 a permis la satellisation, avec une grande précision, de la charge utile double ECS-AMSAT. Les autres lanceurs permettront la mise en orbite de trois satellites Intelsat et un satellite d'observation de la terre.

ARIANE 3 :

La nécessité de mieux affirmer la compétitivité d'Ariane pour les petites charges utiles, a conduit à proposer l'amélioration Ariane 3 dès 1980 avec les objectifs suivants :

- augmenter la performance du lanceur Ariane en orbite de transfert de type géostationnaire jusqu'à 2500 kg afin de permettre le lancement double de charges utiles de type STS PAM ;

- augmenter corrélativement le volume sous coiffe.

Pour respecter ces objectifs techniques, les modifications suivantes ont été retenues :

. Augmentation de la poussée des moteurs Viking des 1er et 2ème étages par accroissement de la pression de combustion de 10 % (53,5 bars à 58,5 bars) ;

. Adjonction de deux propulseurs d'appoint à poudre d'une poussée unitaire de 60 tonnes, fonctionnant dès le décollage durant environ 40 secondes ;

. Augmentation de la masse d'ergols du 3ème étage ;

. Amélioration des performances du moteur du 3ème étage par augmentation de sa pression foyer de 5 bars et allongement du divergent de 200 mm ;

. Adaptation du SYLDA (système de lancement double) développé dans le cadre du développement Ariane 1, au volume requis par les satellites STS PAM.

L'ensemble de ces modifications permet de passer à la configuration Ariane 3. La configuration Ariane 2 est obtenue par suppression des propulseurs d'appoint à poudre.

A ce jour, l'état de développement du lanceur AR3 est le suivant :

. Les études systèmes sont en voie d'achèvement et un premier dossier a été remis à la commission de qualification ;

. Le fonctionnement du moteur Viking à 58,5 bars a été démontré par toute une série d'essais aux limites dégageant les marges de sécurité nécessaire. Le programme d'essai prévu au niveau de la baie de propulsion du 1er étage est terminé avec des résultats excellents. Par ailleurs, toutes les structures modifiées soit par adjonction des propulseurs d'appoint, soit par augmentation des efforts généraux, ont subi leurs essais de qualification avec succès ;

. Les propulseurs d'appoint à poudre sont qualifiés, incluant un tir vertical simulant la fixation des propulseurs d'appoint sur le premier étage. Tous les essais de séparation sont terminés ;

. Les essais de qualification du moteur du 3ème étage sont terminés. Deux essais à feu du 3ème étage au banc d'essai restent à effectuer ;

. Les modifications de la coiffe et du SYLDA sont achevées et qualifiées.

En résumé, la quasi-totalité des essais de qualification au sol est maintenant terminée et le processus de la revue formelle de qualification au sol est commencé, pour un premier vol opérationnel prévu en mai 84. La performance actuellement estimée excède sensiblement l'objectif initial. Les performances pour les missions types sont rappelées en annexe.

Le lanceur Ariane 2 et 3 va succéder au lanceur Ariane 1 à partir de l'exemplaire n° 12. Sa production et sa commercialisation ont été confiées à la Société ARIANESPACE.

ARIANE 4 :

La nécessité d'envisager une nouvelle amélioration du lanceur Ariane est apparue à la suite d'une étude du marché des satellites et de leur évolution en terme de masse à partir de 1985.
Le programme d'amélioration a été décidé début 1982 avec les objectifs ci-après :

. Permettre le lancement double de satellites de la classe 2500 kg et 1400 kg en orbite de transfert de type géostationnaire ou le lancement simple de satellites d'un poids maximal de 4300 kg ;

. Améliorer corrélativement le volume sous coiffe en portant notamment le diamètre utile à 3,65 m ;

. Définir une configuration ou un ensemble de configurations dérivées, présentant un maximum de flexibilité vis-à-vis du modèle de missions.

Pour respecter ces objectifs, les modifications suivantes ont été retenues :

. Augmentation de la masse d'ergols du 1er étage de 147 tonnes à 215 tonnes, tout en conservant le point de fonctionnement des moteurs Viking qualifié durant le programme Ariane 3.

. Adjonction au premier étage des quatre propulseurs d'appoint à ergols liquides, utilisant chacun le moteur Viking utilisé sur le corps central. La flexibilité de la configuration est obtenue en montant soit quatre ou deux propulseurs d'appoint liquide, soit quatre ou deux propulseurs d'appoint à poudre de type Ariane 3, soit aucun propulseur d'appoint dans la configuration de base.

. Modification de la structure de la case d'équipement afin de permettre une meilleure flexibilité d'intégration de la charge utile ainsi qu'une meilleure transition au nouveau diamètre de coiffe.

. Développement d'une structure porteuse externe de lancement double Ariane (SPELDA) permettant les lancements doubles.

Les deuxième et troisième étages ne reçoivent que des renforcements de structure afin de tenir l'accroissement des efforts généraux. Le développement ne comporte pas d'innovations majeures en terme de propulsion puisque, d'une part, la baie de propulsion du premier étage a déjà subi de façon satisfaisante des essais au banc très proches, en durée, du temps de fonctionnement Ariane 4 et aux mêmes conditions de réglage dans le cadre du développement Ariane 3, d'autre part, le système propulsif des propulseurs d'appoint à liquide a constitué une étape de développement du programme Ariane 1.

Par contre, une importante activité système et structures est en cours.

Le premier vol planifié fin 1985 sera effectué dans la configuration 2 propulseurs d'appoints à liquides - 2 propulseurs d'appoint à poudre (44 LP). Les différentes configurations de la partie haute ainsi que les performances associées sont données en annexe.

ENSEMBLE DE LANCEMENT ARIANE N° 2 :

Afin, simultanément, de minimiser les conséquences d'un incident au décollage sur le calendrier de lancement, d'augmenter la cadence possible de lancement et d'en accroître la flexibilité, les états participants au programme Ariane ont décidé la réalisation d'un second ensemble de lancement en juillet 1982. Cet ensemble est en cours de construction conformément au calendrier prévu et doit permettre un premier lancement Ariane 3 en mars 1985 et le premier lancement Ariane 4 fin 1985.

PROJETS FUTURS :

Le lanceur Ariane 4 apparaît remarquablement bien adapté au marché des satellites placés en orbite géosynchrone ou héliosynchrone jusque vers 1993. Au-delà, plusieurs considérations conduisent à la nécessité de pouvoir disposer d'un autre lanceur :

. Le diamètre de coiffe risque d'être insuffisant.

. L'accroissement sensible de la masse des charges utiles implique une augmentation de la capacité totale de lancement afin de permettre toutes les combinaisons possibles de lancement double.

. Le lanceur Ariane 4 est mal adapté à l'orbite basse qui est susceptible, à cette époque, de présenter des perspectives commerciales intéressantes.

. L'érosion progressive de la compétitivité du lanceur Ariane 4 conduit à rechercher toute possibilité d'une nouvelle étape dans l'abaissement des coûts du kilogramme de charge utile en orbite.

Les études de nouvelles configurations ont en conséquence été entreprises depuis trois ans sur les ob-

jectifs suivants :

. Permettre le lancement d'une charge utile de 4500 kg en orbite géosynchrone (ou une combinaison de deux voire trois charges utiles).

. Permettre un lancement d'une charge utile de 15 tonnes en orbite basse avec une fiabilité comparable à celle requise pour les vols habités.

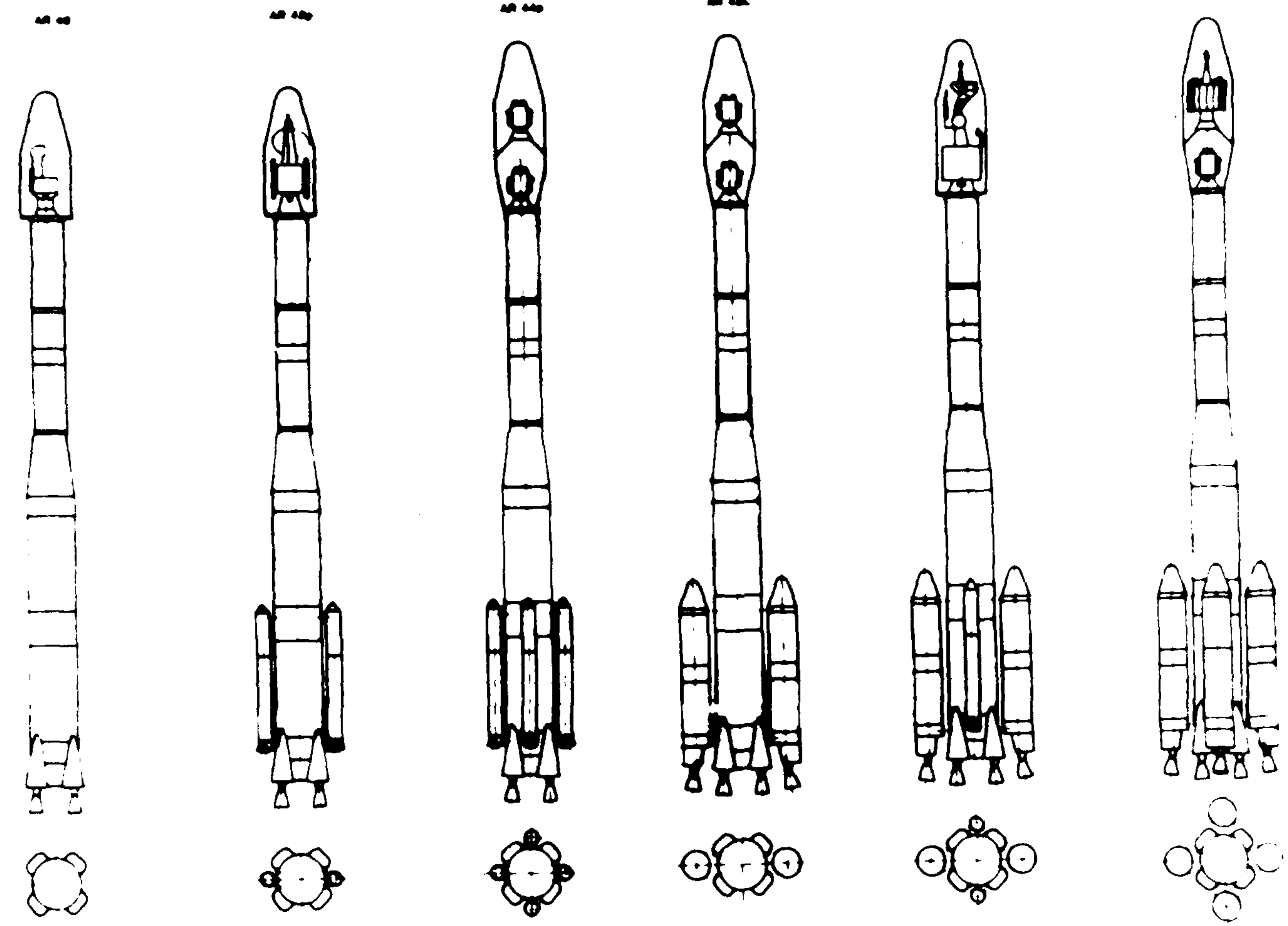
. Offrir un diamètre utile sous coiffe de 4,55 m.

. Offrir une réduction très sensible du coût du kilogramme de charge utile en orbite par rapport à la famille Ariane 4. Corrélativement, soit par l'existence de dérivés à moindre importance, soit par un coût attractif de la version de base, offrir une bonne flexibilité commerciale vis-à-vis des fluctuations du modèle de mission.

De nombreuses configurations ont été étudiées ces dernières années et le choix devrait pouvoir être arrêté mi-84 afin de pouvoir procéder aux études détaillées de la configuration retenue pour une proposition de début de programme fin 1985.

Au stade actuel, ces études qui ont toujours été conduites avec le souci constant de rechercher des optimisations conduisant au coût recurrent minimal, impliquent le développement d'un gros moteur cryotechnique de 90 tonnes de poussée dans le vide. Des études effectuées depuis 1981 sur ce point ont permis d'arrêter les caractéristiques essentielles de ce nouveau moteur dont le développement vient d'être proposé dans le cadre de l'Agence Spatiale Européenne.

ARIANE 4 : DIFFERENTES CONFIGURATIONS



PERFORMANCES D'ARIANE (KG)

CONFIGURATION	ORBITE		
	DE TRANSFERT GEOSTATIONNAIRE	HELIOSYNCHRONE	CIRCULAIRE BASSE
A1	1700	2600	4900
A2	2175	3050	5100
A3	2580	3450	5900
A40	1900	[2700]	-
A42P	2600	Sans objet	-
A44P	3000	Sans objet	-
A42L	3200	> 3500 [4440]	-
A44LP	3700	Sans objet	-
A44L	4200	> 4500 [6100]	[9000]

- performances garanties
- [ ] nécessiteraient des renforts ponctuels de structures
- orbites de transfert géostationnaire

HYPOTHESES

ORBITE DE TRANSFERT GEOSTATIONNAIRE

CONFIGURATION	ALTITUDE DE L'APOGEE (KM) Za =	ALTITUDE DE PERIGEE (KM) Zp =	INCLINAISON DE L'ORBITE i =	ARGUMENT DU PERIGEE ω =
A1	35800	200	10°	180°
A2 et A3	35786	200	8°	180°
A4	35786	200	7°	178°

ORBITE HELIOSYNCHRONE

Altitude Z = 800 Km

Inclinaison de l'orbite i = 98,6°

ORBITE CIRCULAIRE BASSE

Altitude Z = 200 Km

Inclinaison de l'orbite i = 5,2°

COMBAT CAPABLE SPACE SYSTEMS FOR TACTICAL SUPPORT

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SUMMARY

The capabilities of space systems to act as force multipliers in the NATO tactical arena are meaningless unless the ultimate user, the engaged battle force, can be assured of their availability during crisis periods. The Soviet Union has expended substantial resources on antisatellite (ASAT) weapons and electronic countermeasures, including the only demonstrated operational ASAT. The NATO countries must therefore develop systems and strategies to protect their vital space assets.

This presentation describes an overall strategy for providing a dispersed, survivable space system in response to projected Soviet threat capabilities. The physical and electro-optical threats are briefly outlined and countermeasures proposed. While satellite hardening must not be ignored, this paper concentrates on strategies designed to deploy an interconnected space/ground complex so large that attack becomes impractical in terms of resources required for effective neutralization.

Recognizing that space systems exist only to support ground functions dictates that ground networks must also operate in crisis periods. Though a few large ground facilities may be justified as cost-effective in peacetime, these same facilities become critical choke points in wartime. These vulnerable nodes must be augmented by a dispersed network of interoperable mobile ground terminals such as the Transportable/Mobile Ground Station (T/MGS) capable of supporting a wide range of satellites, and the Single Channel Objective Tactical Terminal (SCOTT) which can bring survivable space support directly to troops in the field.

Support from space systems will be vital to the NATO battle commander of the future. Efforts already underway to improve the combat effectiveness of those systems will assure a dependable flow of critical communications and data to the field commander, providing perhaps the margin of victory.

Satellites can provide invaluable service to the NATO forces in communications, positioning, navigation, weather prediction and surveillance. Advancing space technology will provide even more extensive support in the future, but as these new systems develop we must not forget the real reason for the existence of military space programs. Military space systems exist to support battle forces in time of war. Any other use is incidental to this prime mission. Unless the engaged battle force commander can be assured of an adequate flow of timely and accurate data, military space programs are a waste of resources which could be better applied elsewhere.

This fact is certainly understood by the Soviet Union. The Soviets have, over the past twenty years, invested significant scientific and financial resources in the development of counter space weapons systems. They first demonstrated an antisatellite (ASAT) system with the launch of Cosmos 249 in 1968. Since that time they have continually refined and extended their capabilities to destroy orbiting satellites with ASAT or laser weapons, and to interrupt data flow through physical or electronic attacks on space system ground facilities and connecting links. The Soviet ASAT has been flown as part of their war games, and electronic countermeasures (ECM) units are an integral part of Soviet ground forces. Although no dedicated ECM systems targeted against space assets are currently known, the overall strategic intent is clear. The Soviets intend to be able to stop the flow of space system support to NATO tactical units during crisis periods or wartime. (Figure 1)

The NATO powers must therefore develop systems, strategies, and operational procedures to protect their vital space resources in response to the growing Soviet counter space threat. In fact, such development is well underway in several areas of technology.

Satellites are being hardened against electronic and directed energy attacks through the increasing use of new techniques and materials. Sensor optics are being designed to be more resistant to laser blinding. Electronics are being made more resistant to damage from electromagnetic pulse (EMP). Communications links are applying frequency hopping and spread spectrum techniques to guard against interception and jamming. Future military satellites will likely include greatly enhanced maneuver capabilities and even protective systems such as decoys and self defense weapons.

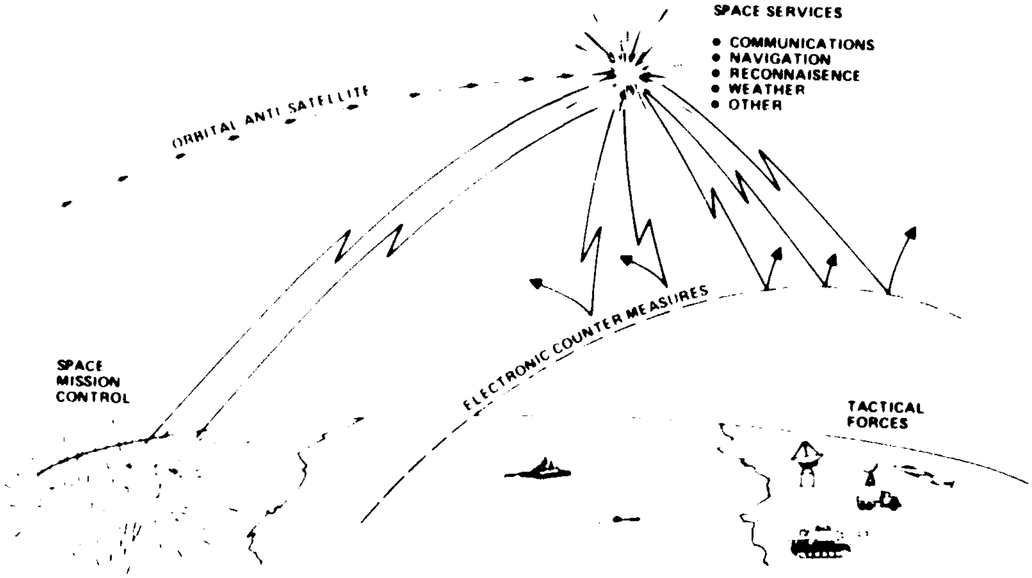


Figure 1. Wartime Effectiveness

In the final analysis, however, a fully hardened and defended military satellite is only a space age "Maginot Line" if it cannot maintain its links with the ground. While satellite hardening will be vital to the survival of military space systems in future wars, hardening alone will not produce the combat capable space systems demanded for tactical operations of the future. Recognizing that military space systems exist only to support terrestrial functions dictates that ground networks must also be able to operate in time of war. The overall military space system includes control facilities, orbiting satellites, users of the data, and communications links connecting these elements. If the Soviet targeting officer can successfully break the continuity of data flow at any point in this system, he has achieved his objective, i.e., the system cannot support the tactical commander. In another sense the targeting officer's job is done if he can cast sufficient doubt in the NATO planner's mind as to the wartime availability of military space assets. If the planner does not expect to be able to use an asset in time of crisis, he is not likely to include it in his war plans. An asset not planned for use will not be used and the enemy wins by default.

With this in mind we now examine a strategy for a possible military space/ground system designed to frustrate the targeter and reassure the NATO planner. This strategy is based on the following assumptions:

a. Any element can be attacked.
b. Some elements are easier to attack.
c. Attack resources are finite.
d. An attack is not successful if the damaged element can be bypassed so that the tactical force is still supported.
e. To be rated as combat capable, a space system must be able to supply dependable support to engaged battle forces.

Targeting can be considered in terms of feasibility and cost/benefit analysis. An element of a military system which is too expensive, in terms of resources required for its destruction, will not likely be high on an enemy target list if the system can be defeated by attacks on some other element. For this reason, hardened satellites represent a much less attractive target than ground elements of current military space systems. Orbital vehicles, if properly protected from laser and ECM attack, are vulnerable only to other orbital vehicles. While this is certainly possible, it would be extremely costly strategy requiring one-on-one attacks by expensive ASAT systems launched in a short time period. Given the cost of space boosters and ASATs and the limited number of launch sites suitable for such system, the targeting officer will probably look for a more effective attack mode.

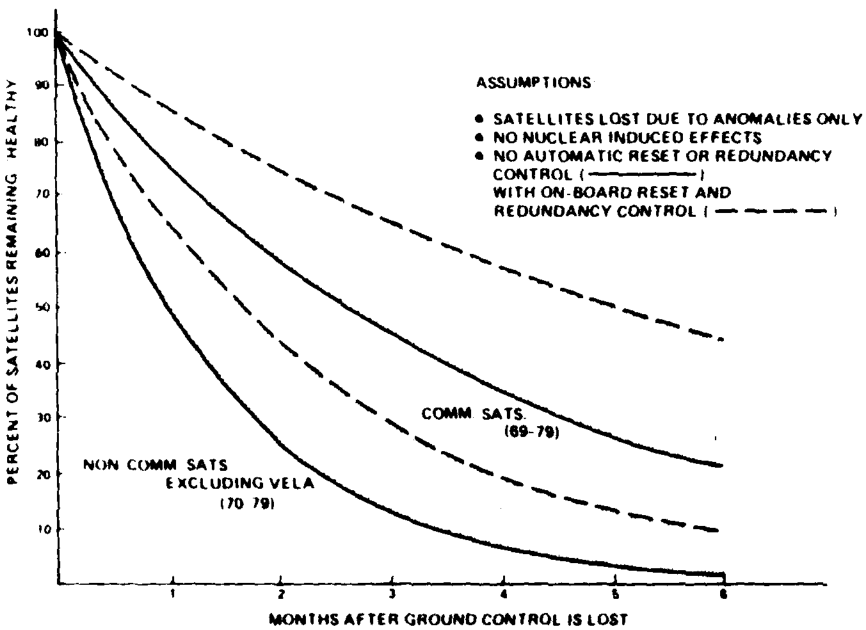
Ground systems and their connecting links to other system elements would seem to offer a much more lucrative target. Military space ground systems today typically are designed for efficient operation during peacetime. A central control element operates one or more ground terminals which perform such satellite support functions as tracking, telemetry, readout and commanding of the orbiting vehicle. In many cases these ground facilities are located in easily accessible areas making them highly vulnerable to either physical or electronic attack at low cost and with unsophisticated technology. Their large 20' - 60' antenna dishes make them easy to locate either from the ground or from reconnaissance satellites. They emit powerful and distinctive electronic signatures for location by Electronic Intelligence (ELINT) collectors, and present a known and stationary target for missiles, bombers, or

saboteurs. Though a few large ground facilities may be justified as cost effective for peacetime research and development, these same facilities become critical choke points in time of war. The military space system must therefore be designed to minimize dependence on fixed ground support.

This independence from fixed ground facilities is proceeding along two (2) distinct paths; autonomous satellites, and mobile ground support. These strategies should be seen as complementary rather than competitive, and will be discussed in turn.

"Satellite autonomy" is often used to describe the ultimate level of satellite system survivability. As the term is generally used, autonomy means on-board task execution and decision making for up to 60 days, assuming normal spacecraft performance. This capability does not currently exist, although limited fault detection and correction and routine maintenance functions can now be performed automatically on-board. Expanding these rudimentary functions is dependent on advancements in fault-tolerant computer technology. Autonomous stationkeeping and navigational functions have been demonstrated by Lincoln Laboratories in their Lincoln Experimental Satellites (LES), but further developments and flight demonstrations are needed before these techniques are widely employed. Adaptive mission sequencing and payload data processing still need substantial development work before they are routinely designed into satellites.

Figure 2 graphically illustrates how the "health" of satellites degrades over time if ground support is unavailable. This graph, based on a study by Aerospace Corporation in 1980, assumes that all satellites are performing normally during the loss of ground contact. It could be argued that the slope of the degradation curves may be much worse in wartime. Satellites are typically unhealthy machines and it is unlikely that all military space vehicles will be in perfect condition when ground support is lost. We could also expect that our opponents would take positive action to degrade the health of those systems which were in good condition. Electronic countermeasures, directed energy weapons, electromagnetic pulse etc., will take a toll on our space systems not reflected in the curves shown in Figure 2.



*BASED ON 1980 AEROSPACE CORPORATION STUDY (ATM 80 (5435-03)-6)

Figure 2. How Autonomous are Satellites Now?

As desirable as autonomy is for space systems, it cannot at least in the next few decades, completely replace ground resources. Figure 3 shows one possible evolutionary trend for autonomy through the year 2000. Increasing hardware and software capabilities on-board the satellite will markedly decrease its dependence on ground stations, but ground support will still be needed for on-orbit checkout and testing, to provide for mission flexibility, and for the correction of unplanned anomalies in critical situations. Just as importantly, for satellite systems to be useful to tactical forces they must maintain links to those forces, either directly or through other space of ground elements, through the highest appropriate conflict level. A fully autonomous, perfectly performing satellite which cannot deliver its data to an appropriate ground element is totally useless as a military system.

Since we cannot in the foreseeable future sever our links to ground terminals, we must direct our attention to the protection of these links in wartime. We must frustrate the targeting officer by providing as backup to our large, vulnerable fixed facilities a widely dispersed inter-connected network of small transportable ground systems depending on proliferation, mobility and concealment for their survival. The term "network" is particularly apt in this context as shown in Figure 4. The

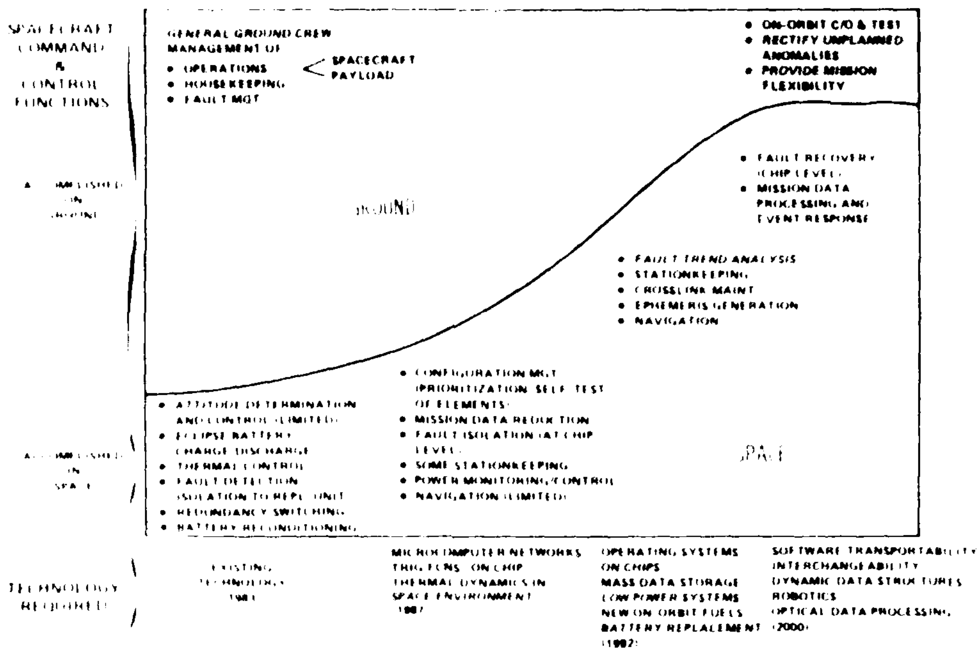


Figure 3. Evolution Towards Autonomous Spacecraft

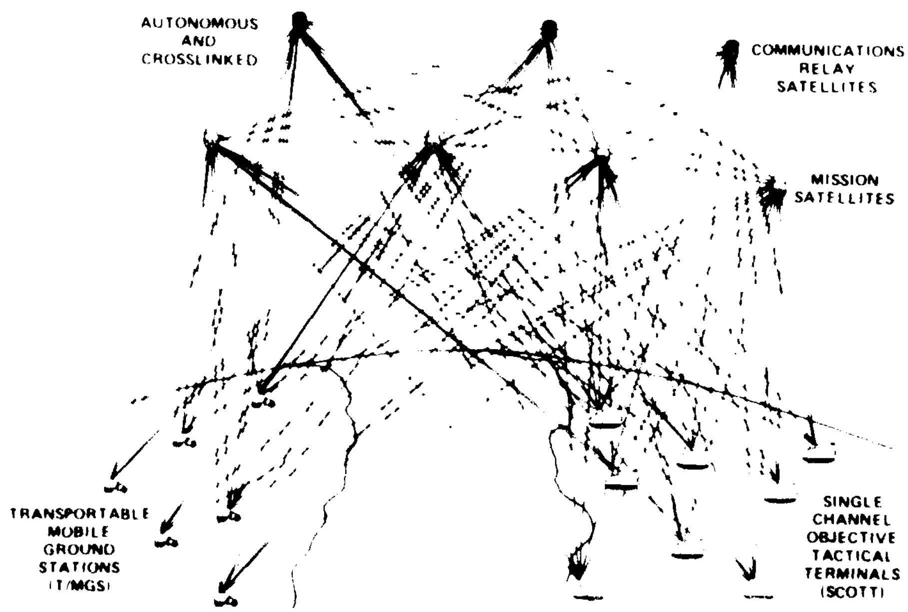


Figure 4. Combat Capable Space System

targeting officer may be able to make holes in the net but a large number of small, dispersed nodes must be successfully attacked to destroy the overall system fabric. Furthermore, the mobility of the ground elements implies that the network is constantly shifting and changing in shape and location, so that reconnaissance information only a few hours old is invalid. Where the enemy had only to destroy a single, known, static facility to render a space system incapable of tactical support,

he is now faced with the almost impossible task of locating, targeting, and attacking a number of mobile facilities which are routinely moved to new positions in less than the locate-target-attack-kill cycle time.

These mobile ground systems can be divided for discussion into two groups by the type of system support they provide. The first group provides the telemetry, tracking, and commanding (TT&C) support needed to maintain the satellite and correct any accidental or man-made anomalies. The second group provides direct contact between the satellite and the user of its services, such as, communications, navigation, etc. In the future more and more of these user terminals will be located directly with the tactical forces they support. The first group is represented here by the Transportable/Mobile Ground Station (T/MGS) (Figure 5) and the second group by the Single Channel Objective Tactical Terminal (SCOTT) (Figure 6). These are examples of the systems which will anchor the two ends of the combat capable space network of the future.

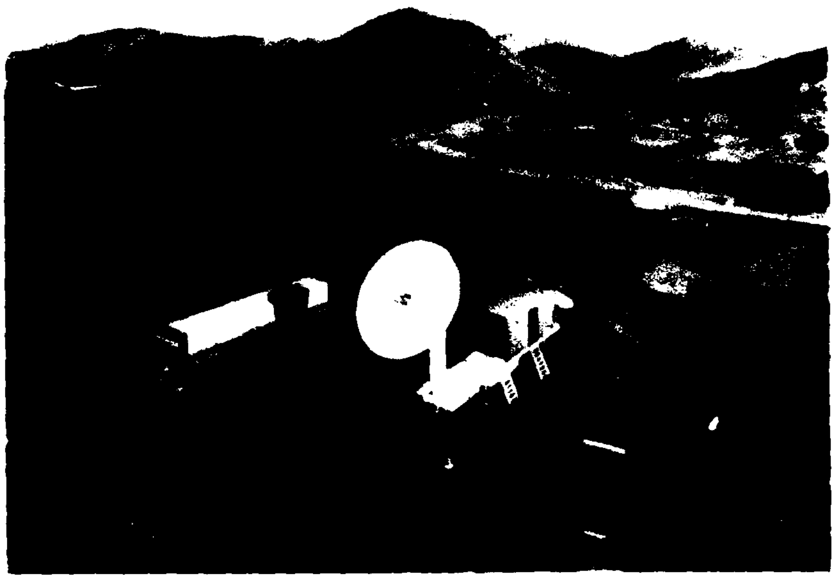


Figure 5. TMGS

Although spacecraft may have unique requirements, most have similar needs for TT&C support and most military systems are supported by the Air Force Satellite Control Facility (AFSCF) common user network in either a prime or backup mode. The T/MGS is being developed to provide TT&C support for the great majority of the programs in the AFSCF mission model, some eleven different satellite systems. The initial T/MGS, to be delivered in Dec. 1985, will utilize state-of-the-art technology. Models to follow will incorporate Pre-Planned Product Improvement (P^3I) modifications to respond to better defined threats and operational requirements. For example, the T/MGS could have an EHF capability as early as requirements dictate. This would allow for a smaller, more survivable ground station, but at the current time military satellites are not using EHF, so T/MGS will have an S-band system.

Performance goals for the initial system scheduled for delivery in December 1985 include:

- o Support to low, medium and geostationery altitude satellites
- o Stand-alone TT&C data processing
- o Voice/data communications with Air Force Satellite Control Networks (AFSCN) and users
- o Use of government furnished software
- o G/T: 16.8 dB/k
- o EIRP: 98.3 dBm
- o Maximum telemetry data rate of 128 kb/s
- o Maximum command data rate of 2 kb/s
- o Network communications via wideband and narrowband
- o DSCS satellite communications via X-band SATCOM terminal
- o S-band communications relay at 32-256 kb/s
- o Mean-time between failures goal of 396 hours
- o Mean-time to repair goal of 4 hours
- o Maximum utilization of off-the-shelf equipment

Figure 6. SCOTT

The T/MGS is designed to operate either in a stand-alone mode or in conjunction with other fixed or mobile TT&C centers. It can receive, store, and forward data using the S-Band Mission 22 relay or it can be configured as a "bent-pipe", passing data from a satellite or another control station through to another element with no local processing or delay. The T/MGS is also capable of supporting the TT&C requirements of programs which, due to their survivability requirements, have mobile mission data processing systems operated in accordance with the survivability concept developed for the particular satellite system.

The T/MGS will be air transportable in C-130 aircraft and will be ground mobile over reasonable road surfaces. It will be self sufficient in both power generation and communications. Protection from electromagnetic pulse(EMP) will be designed into the overall system and the appropriate subsystems. The T/MGS is not required to operate while in transit but will be assembled, operated, disassembled, and moved to a new location as circumstances demand. Erection and tear-down times must therefore be kept as short as practical to maximize both survivability and operational effectiveness.

As the T/MGS program progresses, a pre-planned product improvement effort (P^3I) will proceed in parallel to incorporate appropriate new technological advancements at minimum cost and risk, commensurate with evolving threats and system performance requirements. Constant advances in micro-circuit design should dramatically reduce the size and power requirements of future electronic systems. As the data system for a T/MGS shrinks from the size of a trailer to the size of a desk, it will require much less support from power generation and air-conditioning systems so that these too can be smaller. The transition to higher frequencies such as EHF allows for much smaller ground antennas on the order of one or two meters rather than the 7 to 10 meters required for the current S-band system. This will yield a further reduction in the size of the ground station and more importantly, eliminate the need to disassemble the station for road mobility, thus greatly increasing system survivability and operational availability. As these smaller, more mobile, and probably less expensive stations proliferate, trade studies will be necessary to determine whether they should be structured into program-dedicated or common-user networks to best support military space systems.

Still, in the context of space support to tactical operations, survivable TT&C is only one part of the overall system. To be combat capable, a space system must reliably deliver its product to the battle force element in need of its service. This requires that the tactical unit be provided with the necessary equipment to access the space system. Such equipment could be as simple as a handheld receiver for position determination using the Global Positioning System (GPS), to large shipboard terminals to receive communications and weather data from satellite systems. The Single Channel Objective Tactical Terminal (SCOTT) falls somewhere between these two extremes and presents an interesting preview of future tactical access to space assets.

The SCOTT is being developed by the U.S. Army to operate with the MILSTAR survivable military communications satellite. The MILSTAR system will operate in the EHF band at 20-44 GHz and will provide much more secure and jam resistant communications than are currently available. The SCOTT, either track vehicle mounted as shown in Figure 6 or in some other appropriate configuration, is the tactical commander's link with the world through the MILSTAR networks.

The Army requirement for EHF stems from its basic communications requirement. Objectives defined in the beginning of SCOTT's development include making the terminal highly mobile, and easy to operate. Survivability is a priority, as is reliability, maintainability, and supportability. It will also be required to interoperate with TRITAC equipments. Finally, all of this needs to be wrapped in an affordable package because of the large number of SCOTT terminals being considered.

The ground segment consists of one rack of transmission equipment, the antenna system, and ancillary equipments. These three subgroups will be installed in any of the current shelters; the S-250 mounted on the 5/4 ton truck the S-280 mounted on a 2 1/2 ton truck, and the M-577 command track vehicles. Two advanced development models are currently being fabricated at Massachusetts Institute of Technology's Lincoln Laboratory; one of these will be installed in the track vehicle configuration. Current weight estimates range between 400 lbs and 500 lbs; however, more definitive weight studies are now in progress.

The antenna system includes the transmitter and small dish antenna with a dual frequency feed. The canister will be mounted on the vehicle in such a way as to permit removal for remote operation. Two such configurations are currently being considered for the M-577 track vehicle. The earlier concept has the canister dropped into an armor box, located at the front curbside corner of the vehicle. This same box would also house the paging antenna, designed to allow SCOTT to be alert in motion. A more recently proposed configuration would have the antenna canister dropped in a build-in canister, located at the rear curbside corner of the vehicle.

SCOTT operation begins with satellite acquisition. The operator, knowing his location within 10 km, can make successful acquisition. The acquisition process includes raising the antenna dish, then rotating the dish until the satellite is acquired. SCOTT is then ready for transmission by up to four users. The terminal can be used to provide the full range of space services to the ground force commander, including communications with other units or with higher headquarters anywhere in the world.

The T/MGS and SCOTT terminals are only two of the more obvious sources of space support to the tactical commander.- Once tactical planners gain more confidence in the survivability of space system in wartime, even more ways will surely be found to apply space support as a force multiplier. U.S. military planners are even now considering space as the "high ground of the future". NATO planners cannot afford to do otherwise; these emerging capabilities must be used, and used wisely. Survivable space systems made up of mobile ground support, hardened cross-linked satellites, and proliferated tactical access terminals may well provide the margin needed for victory in some future conflict.

The discussion which followed this presentation appears in classified publication CP344 (Supplement).

THE SPOT OPERATIONAL REMOTE SENSING SATELLITE SYSTEM: CURRENT STATUS AND PERSPECTIVES

by

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ABSTRACT

The SPOT programme under the auspices of the French National Space Agency (CNES), is implemented by France in association with European partners (Belgium and Sweden). It comprises the earth observation satellites and the ground receiving stations.

The first satellite, due for launch in 1985, will carry a payload comprising two identical HRV (High Resolution Visible) instruments using CCD linear arrays technology. These will make images of the earth with a sampling step of 20 meters in three color bands in the visible range and in the near infrared, and with a sampling step of 10 meters in a broad, panchromatic band : i.e. in black and white. This configuration is suitable for observing the small agricultural plots found in many countries. It also satisfies some conventional cartographic requirements.

Each instrument has a flat mirror which can steer the line of sight in a plane perpendicular to the track of the satellite. The steering range is $\pm$ 27° about the geometric direction, in 91 discrete steps of 0.6°, this translates on the ground as a geographic band of up to 475 kilometers on either side of the satellite's ground path to be explored. Due to the curvature of the earth, the maximum angle of incidence with the ground is 33°.

The sidelooking capability will allow the satellite to observe any region of the Earth at intervals of one to several days, thus allowing relatively fast changing phenomena to be monitored. It will also be possible to provide for stereoscopic vision by associating views taken from different angles.

The SPOT satellite has a total mass of approximately 1750 kg at the beginning of its life, and will be placed in a sun synchronous, circular orbit at 832 km altitude by the European Ariane satellite launcher.

*Since 1 August 1983, Chairman and Chief Executive Officer SPOT IMAGE, Toulouse, France

The nominal lifetime of the first satellite is two years. A second satellite, identical to the first one, has already been ordered for a launch nominally in 1986 in replacement of the first one. Further satellites to provide continuity of service over a longer period of time are under consideration.

SPOT will be used, among many applications, for :

. studies on land use and the evolution of the environment

. evaluation of renewable natural resources (agriculture, forestry)

. assistance in surveying mineral resources

. medium-scale mapping in the range of 1:100.000, map updating at scales about 1/50.000, and preparation or updating of thematic maps at scales from 1:50.000 to 1:25.000.

The organisation for SPOT data marketing and distribution relies on the SPOT IMAGE Company which is established as a subsidiary of CNES and other french agencies and corporation involved in land remote sensing activities. SPOT IMAGE will distribute on a commercial basis the SPOT data recorded on board the spacecraft and transmitted to central receiving facilities in Toulouse (France) and Kiruna (Sweden). In addition, direct broadcasting to foreign receiving stations is being encouraged in order to improve data distribution on a national or regional basis.

SPOT might very well be the first truly operational land remote sensing satellite system, although other programmes are on the planning stage both in the U.S. (post Landsat-D) and Japan (ERS programme). Although primarily a civilian applications oriented programme, the technology base it will use may be of value for surveillance or reconnaissance applications.

1 - THE SPOT PROGRAM

The SPOT program has been planned and designed as an operational and commercial system. Decided by the French government in 1978, with the participation of Sweden and Belgium, the program is managed by the French Space Agency (CNES) which is responsible for the system development and satellite operations. SPOT 1 will be launched in early 1985 and SPOT 2, to be available for launch in early 1986 is also under construction. Plans are being made for the launch of SPOT 3 and 4 already in 1988 onwards in order to ensure the necessary service continuity expected from an operational spaceborne remote sensing system. Indeed it is essential that new systems be operational over a sufficiently long period (at least 10 years) to allow the development of applications in those areas where remote sensing is not yet widely used.

The institutional organization of the SPOT operations has also been set up. CNES is in charge of spacecraft procurement, launch and operation and SPOT IMAGE, a commerical corporation, in charge of data distribution and all commercial relations with data users. SPOT IMAGE is developing a network of agents, distributors and subsidiaries to serve local markets; it is in the process of finalizing a pricing policy for SPOT data which is based on eventual complete cost recovery for the system (both investments amortization and operations expenses). Market studies indicate that this objective can be reached within the next ten years if the market develops as expected.

2 - THE SPOT SYSTEM AND DATA DISTRIBUTION

2.1 SPACECRAFT CHARACTERISTICS

The SPOT spacecraft carries two identical sensors, called HRV (Haute Resolution Visible), made of static solid state arrays of detectors (CCD) and operating in the visible and near infrared part of the spectrum. Among the innovative features of SPOT are the relatively high ground resolution of the imagery it will produce (10 m in the panchromatic mode, 20 m in the multispectral mode) and the ability of its sensors to point up to 27 degrees East and West of the local vertical axis. This latter feature offers interesting possibilities to increase the number of opportunities to obtain views of a given area. It also permits stereoscopic observations by combining views taken at different angles from the vertical and therefore opens up the possibility of third dimension (or altitude) determination, an important requirement for cartographic applications. The principal characteristics of SPOT are summarized in table I.

Swathwidth

The two identical sensors (HRV) can be activated independently. Each instrument has a swathwidth of 60 km. When the two instruments operate in adjacent covering field, the ground coverage is 117 km.

Imaging Modes

SPOT operates in two modes: multispectral mode and panchromatic mode.
In the multispectral mode, observations are made in three spectral bands with a pixel size of 20 meters.

. a green band from .50µm to .59µm
. a red band from .61µm to .68µm
. a near infrared band from .79µm to .89µm

SPOT : PRINCIPAL CHARACTERISTICS	
ORBIT	Circular at 832 km Inclination: 98,7 degrees Descending node at 10h 30mn A.M. Orbital cycle: 26 days
HAUTE RESOLUTION VISIBLE (HRV)	Two identical instruments Pointing capability: ± 27 degrees East or West of the Orbital plane Ground swath: 60 km each at vertical incidence Pixel size: . 10 m in panchromatic mode . 20 m in multispectral mode Spectral channels: . panchromatic: .51 to .73 µm . multispectral: .50 to .59 µm .61 to .68 µm .79 to .89 µm
IMAGES TRANSMISSION	Two on board recorders with 23 minutes capacity each Direct broadcast at 8 GHz (50 Mbits/sec)
WEIGHT	1750 kg
SIZE	2 x 2 x 3.5 m plus solar panel (9 m)

Table 1

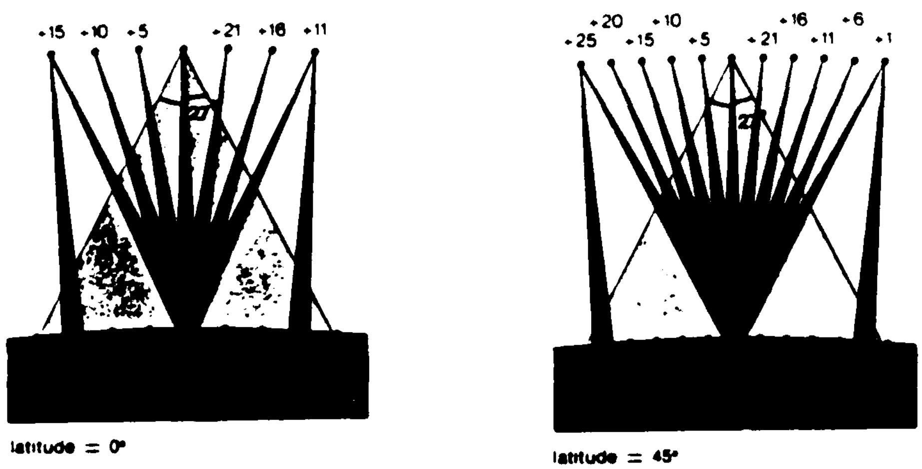


Figure 1 : Typical sequence of acquisition at the Equator and at latitude 45°

In the panchromatic mode, observations are made in a single broad band, from .51µm to .73µm with a pixel size of 10 m.
The multispectral bands have been selected to take advantage of interpretation methods developed over the last ten years; they have been designed to allow the best discrimination among crop species and among different types of vegetation using three channels only.
The panchromatic band will offer the best geometric resolution (10m) and will make possible to comply with cartographic standards for maps at a scale of 1:100,000 and/or to update at a scale of 1:50,000 and in some cases 1:25,000 for thematic applications.

Field pointing flexibility, Nadir and off nadir viewing

One of the key features of SPOT is the steerable mirror which provides off nadir viewing capability.The instrument can be titled sidewards (to the East or to the West) step by step from 0 to 27 degrees allowing scene centers to be targeted anywhere within a 950 km-wide strip centered on the satellite track.
This technique provides a quick revisit capability on specific sites. For instance, at the Equator, the same area can be targeted 7 times during the 26 days of an orbital cycle i.e. 98 times in one year, with an average revisit period of 3.7 days. At latitude 45 degrees, the same area can be targeted 11 times in a cycle i.e. 157 times in one year, with an average period of 2.4 days, a maximum timelapse of 4 days and a minimum timelapse of 1 day (Fig. 1).
The revisit flexibility allows

1. to monitor phenomena which rapidely vary over time, such as crops, environmental stresses, natural disasters.
2. to improve the possibility of obtaining timely data required in many studies
3. to improve the rate of area coverage by minimizing the effects of weather conditions.

Figure 2 illustrates the variability to obtain a complete coverage of France using cross-track viewing capability. At vertical viewing the coverage is obtained in 313 days, and in 100 days only if the depointing mode is used.

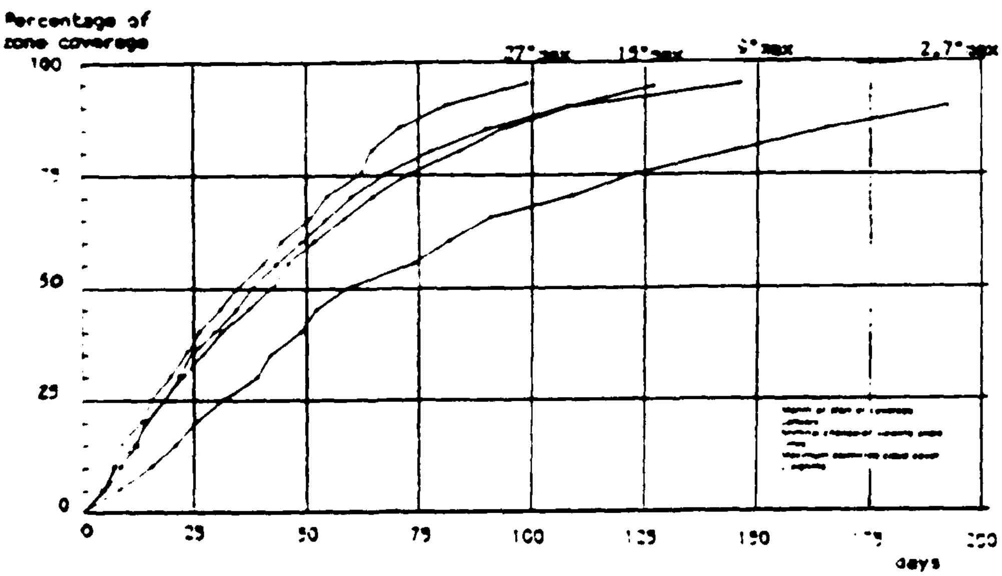


Figure 2: Time required to obtain a complete coverage of France for different maximum cross-track viewing capabilities

Stereoscopy
The off nadir viewing capability also permits stereoscopic observations by combining views taken at different angles from the vertical. The 3D vision is obtained with the same area recorded from two different orbits, creating a parallax effect between the two scenes. Stereopairs are an important requirement in many cartographic applications: geomorphical, geological or soil maps and of course for topographic maps. SPOT will provide the opportunity to map anywhere in the world with a mapping accuracy corresponding to the 1:100,000 standards.

Images transmission
Direct broadcasting operates at 8 GHz at a rate of 50 Mbits/sec. The satellite carries two on board recorders with a 23 minutes capacity each. On board data recording will be used over areas where no ground receiving facility are available.

2.2 DATA ACQUISITION, PREPROCESSING AND DISTRIBUTION

Information availibility through easy and quick access to data and products is a very important factor in operational procedures. The system implemented for data acquisition as well as data distribution has been conceived to meet the user needs and SPOT customers are given an active part in the system.
Basic principles are:
- a permanent information regarding data availibility
- a flexibility "on request" data acquisition
- a fast data and products distribution, based on a non discriminatory policy and the definition of marketing zones between SPOT IMAGE and various distribution centers
- the protection of SPOT data by a copyright

2.2.1 SPOT ground segment

The SPOT system consists of:
- a satellite mission and control center operated by CNES
- two main ground receiving stations and preprocessing centers located at Aussaguel near Toulouse, France and at Esrange-Kiruna in Sweden. These stations receive direct data over the North polar zone, Europe and North Africa as well as worldwide data recorded on the two satellite tape recorders. Each station has a receiving capacity of 250 000 scenes per year.
  The preprocessing centers attached to both stations and operating in Sweden and in France, have a capacity of 70 system corrected (level 1) scenes per day or 20 precision processed (level 2) scenes per day. A level 1 scene can be preprocessed within 48 hours from its acquisition at the ground station, while a precision processed scene requires 5 to 7 days.
- a network of regional receiving stations located around the world. These stations have concluded reception agreements with SPOT IMAGE. Acquisition programs over the visibility area of each station is made by station operators and/or SPOT IMAGE.
- a distribution network managed by SPOT IMAGE on the basis of commercial agreements and marketing areas. Distribution involves standard data as well as value-added products.

2.2.2 Data bank information: the catalog system

SPOT IMAGE will build up a general catalog of SPOT images which will contain data concerning images received and archived by all stations in the world. The catalog system is fully computerized and designed to operate 24 hours a day, 365 days a year. It will contain for each scene, information concerning: the location (geographical coordinates, orientation, etc...), acquisition mode (multispectral, panchromatic, viewing angle, stereopair), scene identification (grid number, date), quality (telemetry, cloud cover), archived products already available.

The SPOT catalog will offer users a wide range of options concerning the processing and presentation of catalog data. It includes statistical calculations concerning image characteristics, definition of image families and scene selection according to various criteria; alphanumeric or graphic display will be available. Besides scene characteristics and image selection, the system will analyze users data requests, record and manage data orders and manage the data acquisition programs.

Users will access the catalog directly in Toulouse, by conventional means (mail, telephone, telex) or through data transmission network (Transpac, Euronet, Tymnet, Telenet, Datapac,...).

Information exchanges between SPOT IMAGE and SPOT data users will also be possible through an electronic mailbox system. With an electronic key, users will be able to deposit in the catalog system memory messages regarding requests for information, programming or orders. Stored messages will be read over every 6 hours and the replies deposited at users disposal.

For users convenience, it is expected that at least one point of contact by country (SPOT distributor) should be equiped with a fast transmission link to the SPOT IMAGE worldwide catalog.

2.2.3 Data acquisition

This is an innovating feature of the SPOT system. When an image is not available in archive or when a SPOT user wishes to acquire specific data with a specific time scheduling, he can request a SPOT acquisition program. For this, the user can apply directly to SPOT IMAGE (via the catalog system) or to a local receiving station or to a local SPOT IMAGE distribution center.

According to the case, the user may request:

- unique coverage obtained during a certain period of the year
- multitemporal coverage, meaning a number of coverages acquired at different periods,
- stereoscopic coverage, i.e. two coverages acquired in specified conditions in relation to the viewing angles used.

To do this, the user must first define the geographical area to be covered, in the form of geographical coordinates, of a polygon or a circle.

For each coverage the user wants to obtain he must then indicate the general characteristics and constraints relative to image recording and especially:

- image recording: mode multispectral and/or panchromatic
- image recording periods,
- the viewing angle or the range of variation comprised between -24°6 and +24°6,
- the cloud cover threshold accepted from 0 to 2 per quarter of an image,
- eventually, the gain to be applied to detectors; 2 possibilities: low and high.

According to the user's needs, which are translated into programming parameters, SPOT IMAGE carries out a technical feasibility study of the request in coordination with the Mission Control Center. In the standard procedure, a report is handed back by SPOT IMAGE within a delay of 48 hours to 4 days.Accelerated procedure can be used in the case of emergency. It will comprise, among others, the geometrical conditions of image recording (mosaicing of the zone to be covered), and its feasibility (probability of execution in time taking into account the climatic data of the region considered).
The user may accept (or not) these propositions. He may also modify the initial request, in which case a new study is undertaken. When the user accepts the technical conditions of execution proposed, an agreement is made between SPOT IMAGE and the user stipulating the technical and financial conditions of the execution of the program.
SPOT IMAGE, in liaison with the user, can modify the execution of a program in different ways:
- by programming directives (modification of parameters, cloud cover level, viewing angles, restriction of the range of variation),
- by changing from a fixed single angle to a range of variation, in order to terminate a program ("clean-up" mode)
- by changing the end of period date (may be delayed)

The final validation of scenes is carried out after examining the quick-look images.
The user may receive periodically or on request, a detailed report on the state of progress of his program. This report supplies all validated scenes and the progress of coverage of the geographical zone (in simplified graphic form with statistics or in geographic/contour form).
Acquisition programs will include long term monitoring programs as well as emergency acquisition procedures (in case for instance of natural disasters).

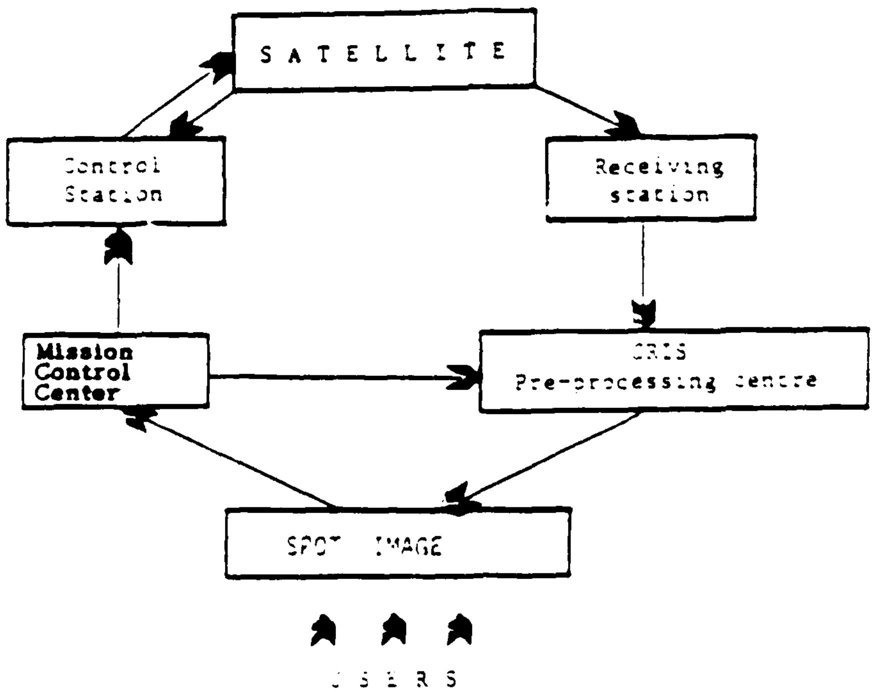


Figure 3: SPOT system diagram

2.2.4 Data and products distribution

The Toulouse preprocessing facility (CRIS Toulouse) is designed to produce standard data such as: a level 1 (system corrected) scene within 48h and level 2 or S (precision processed) within a week, with a maximum capacity of 70 scenes per day at level 1 or 20 at level 2. The Kiruna preprocessing center (CRIS Kiruna) will have similar capacities.
SPOT IMAGE will reproduce and deliver to users standard data on CCTs and films coming from the preprocessing centres. Special and value added products will also be made available to users through a worldwide distribution network.
The term "SPOT Data" applies to all SPOT scenes with standard processing while "SPOT Product" refers to any product derived from the above defined data.
Whereas the distribution of SPOT Data is subject to specific rules and geographical limitations, the distribution of SPOT products i.e. value-added products is not subject to any such restriction except copyrights.
CNES owns the copyright on all SPOT data. This means that any organization that wishes to distribute or sell SPOT data must first obtain a sub-license from SPOT IMAGE which has been granted by CNES an exclusive world-wide license for the distribution of SPOT data.
SPOT receiving stations will be automatically granted an exclusive sub-license for the distribution of SPOT data within their distribution zone. This sub-license is exclusive, insofar as SPOT data is concerned, within the station's distribution zone; such zones generally covering the country (or group of countries) operating the station.
SPOT IMAGE has exclusive SPOT data distribution rights in those countries that do not possess a receiving station and is currently negotiating agreements with companies, agents and the like in these different countries with a view to ensuring close contact between distributors and users and the efficient distribution of both data and products.

3 - THE SPOT DATA SIMULATION PROGRAM

In order to prepare the user community to the use and analysis of SPOT images, an ambitious SPOT data simulation program has been initiated since 1980.
It is managed by the french "Groupement pour le Développement de la Télédétection Aérospatiale (GDTA) of which CNES is member; it includes two types of images simulations:
- geometric simulations whereby mosaics of aerial photographs are digitized and resampled to 10 meters to simulate the geometric characteristics of SPOT images under different viewing angles (this requires a digital terrain model of the aera in order to take account of terrain relief in the simulation). Those simulations are used to study the usefulness of SPOT data for topographic mapping and other applications requiring stereoscopic coverage.
- radiometric simulations, whereby images of certain areas are collected via an airborne scanner and data from the different channels of the scanner are processed to simulated the three spectral bands of SPOT with resampling at 20 meters intervals. Such simulated images do not have the geometric quality of SPOT images, but reflect their expected radiometric characteristics and therefore their ability to classify different types of terrain, vegetation cover, crops, etc. Many sites in France, in other european countries as well as in Africa, Bangladesh and the United States

have been covered and provide a variety of usefull examples for data analysis and applications. The data itself, as well as information booklets on the image interpretation are available from SPOT IMAGE. *

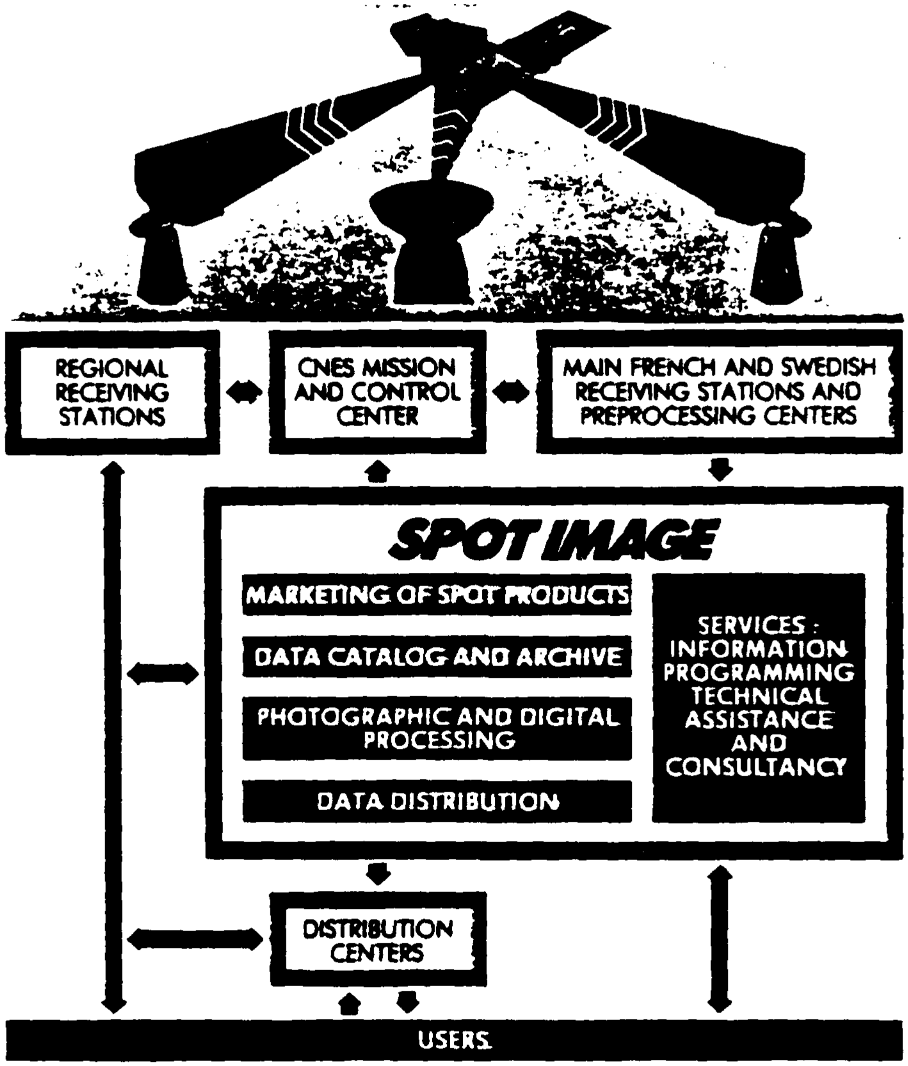
This SPOT data simulation program has involved a large number of scientists and investigators in all countries where sites have been surveyed; it has proved to be of high interest both to the investigators and to the producers of the data and should pave the way to a fruitfull interaction between the user community and the SPOT data producers/distributors when the spacecraft will be operating.

* For the simulation data in the United States, contact

SPOT IMAGE Corporation
1150 17th Street
Suite 307
Washington, D.C. 20036
Tel: (202) 293-1656
Telex: 4993073

SPOT IMAGE

SPOT IMAGE AND THE SPOT SYSTEM



SPOT IMAGE

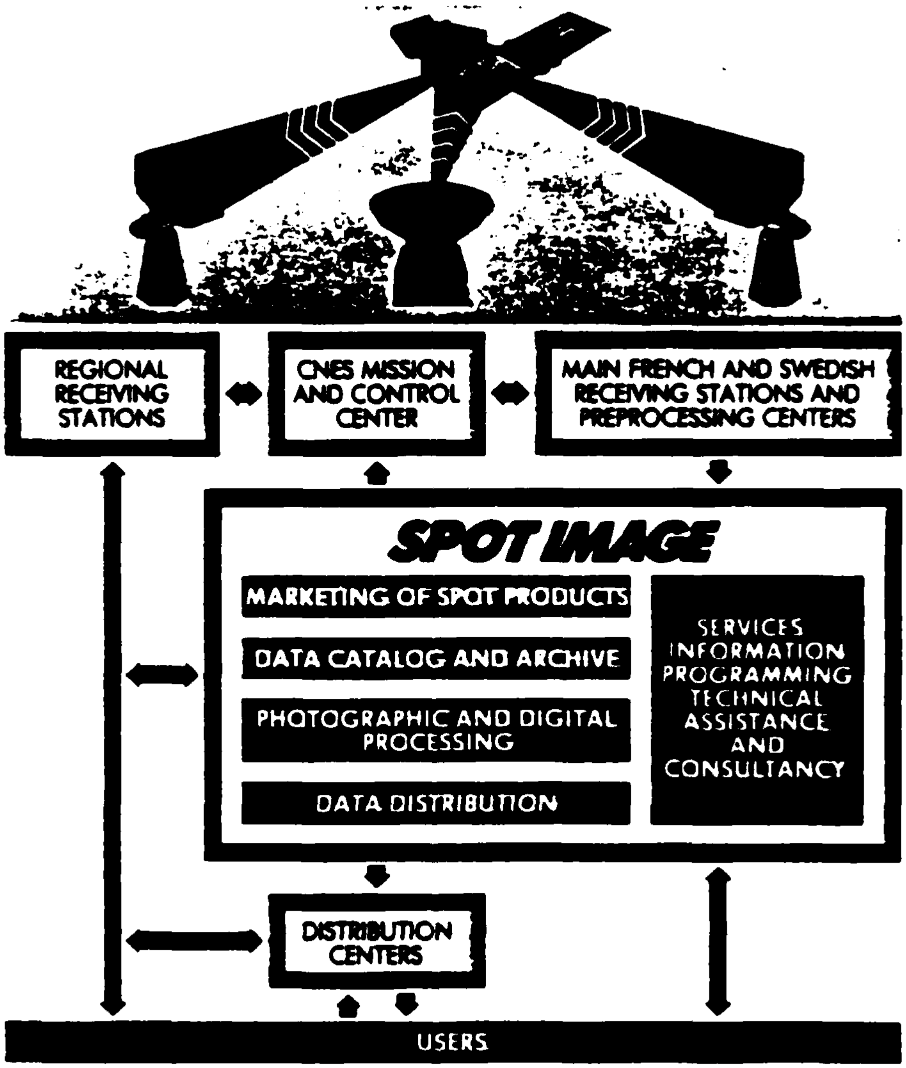
SPOT PRODUCTS

EACH 60 × 60 KM SPOT SCENE WILL BE AVAILABLE :

- AS PANCHROMATIC DATA (ONE BAND, 10 M.) OR AS MULTISPECTRAL DATA (THREE BANDS, 20 M)
- AT FOUR PROCESSING LEVELS :
  - **1 A** EQUALIZATION OF DETECTOR RESPONSE NO GEOMETRIC CORRECTION
  - **1 B** RADIOMETRIC CORRECTION AND GEOMETRIC CORRECTION INDUCED BY THE ACQUISITION SYSTEM
  - **2** RADIOMETRIC CORRECTION PLUS PRECISION GEOMETRIC CORRECTION TO MAP THE IMAGE INTO A CARTOGRAPHIC PROJECTION
  - **S** REGISTRATION WITH A REFERENCE SCENE
- IN SINGLE FRAME (AT NADIR OR OFF NADIR VIEWING) OR IN STEREOPAIR
- ON PHOTOGRAPHIC FILM AT SCALES RANGING FROM 1/400,000 TO 1/25,000 OR ON CCT (1600 OR 6250 BPI)

SPOT IMAGE

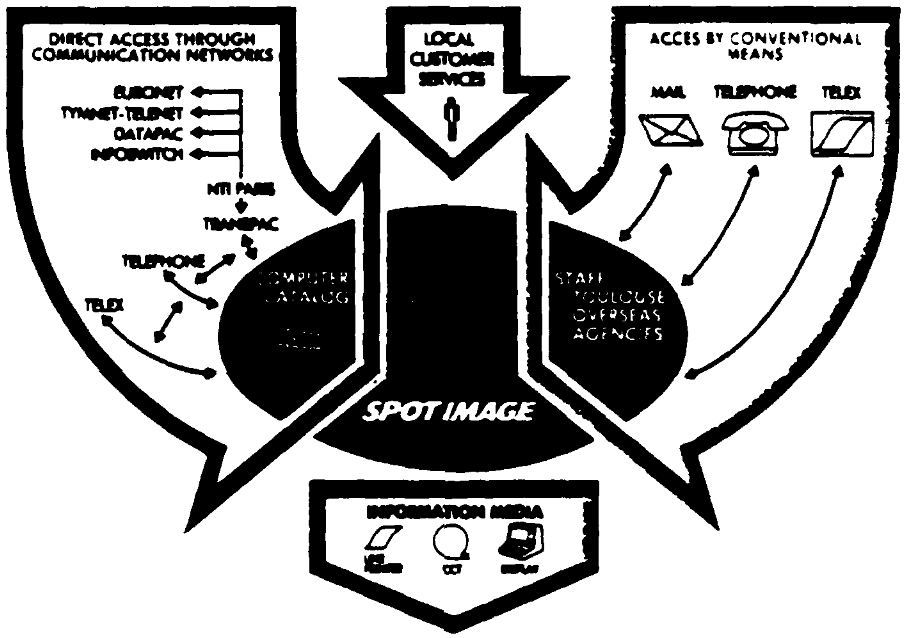
SPOT IMAGE AND THE SPOT SYSTEM



SPOT IMAGE CATALOG

A CATALOG SERVICE FOR SPOT IMAGE DATA BANKS WORLD WIDE

24 HOURS A DAY INTERACTIVE REMOTE ACCESS THROUGH COMMUNICATION NETWORKS



THE SYSTEM WILL PROVIDE :

- THE CHARACTERICTICS OF ALL SPOT SCENES AVAILABLE THROUGHOUT THE WORLD (IDENTIFICATION, ACQUISITION MODE, QUALITY)
- THE IMAGE SELECTION ACCORDING TO VARIOUS CRITERIA (GEOGRAPHICAL AREA, DATE, QUALITY)
- THE POSSIBILITY TO COMPUTE IMAGE STATISTICS AND TO COMPILE GRAPHIC MOSAICS OF SPOT COVERAGE.
- CUSTOMER DATA REQUEST ANALYSIS
- DATA ORDER RECORDING AND MANAGEMENT
- ACCESS TO SATELLITE PROGRAMING SERVICES AND ACQUISITION PROGRAM.

THE ESA REMOTE SENSING SATELLITE SYSTEM (ERS-1)

by
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SUMMARY

The ERS-1 Remote Sensing System is presently in the definition phase. The system development will start in eraly 1984, launch of the first satellite is planned for mid 1988 from Guyana Space Centre by the European launcher ARIANE. The ERS-1 system development will be performed jointly by the member states of the European Space Agency together with Norway and Canada.

1. MISSION OBJECTIVES AND SYSTEM ELEMENTS

Mission Objectives

The ERS-1 system will contribute to the exploitation of coastal and global oceans, specifically those troubled by ice and to the development of an improved global weather information service. On an experimental base, microwave imaging over land will also be performed by the ERS-1 system as an all weather complement to optical data provided by other satellites.

The prime mission objectives are twofold:

- collection of data for scientific use and
- dissemination of ocean data for commercial application.

Data, Scientific Use

The data use for scientific purpose will increase the understanding of the ocean processes including those in coastal zones and polar regions. The data when processed alone or or processed in conjunction with data from other satellites or earth surface devices will contribute significantly to the advancement of physical oceanography, glaciology and climatology.

Data, Commercial Use

Data distributed for commercial use will primarily improve the short term and medium term forecast of weather and ocean condition anywhere on the globe. This will benefit the design, planning and operations of oil platforms and also aid the optimization of ship routing. Monitoring of surface pollution is also considered in order to predict the trajectory of pollutants and their potential threat to sensitive shore areas.

Instruments and Measurements

In order to undertake the described mission, a set of space-borne instrumentation supported by a ground-based network for processing, dissemination and archiving is contemplated. The space-borne instruments and their measurements are the following:

- an Active Microwave Instrument (AMI) operating in the C-band with the aim of measuring wind fields and wave image spectra and providing all-weather high resolution images of coastal zones, open oceans, ocean ice areas and on an experimental basis, images over land;

- a Ku-band Radar Altimeter (RA), with the aim of measuring significant waveheight, wind speed, and providing measurements over ice and major ocean currents;

- Laser Retroreflectors (LR) for accurate satellite tracking from the ground, as a complementary instrument for the Radar Altimeter;

- an additional Announcement of Opportunity Package presently consisting of:
  - . the Along-Track Scanning Radiometer with a Microwave sounder (ATSR/M). The radiometer is for sea surface and cloud top temperature determination and general radiance measurements. The microwave sounder is for the accurate determination of the water vapour content in a vertical atmospheric column
  - . the Precise Range and Range Rate Experiment (PRARE), is an altitude and altitude change measuring device utilizing a ground transponder network. It includes ionospheric error correction capability.

Table 1 gives the main geophysical measurement objectives in terms of geophysical parameters to be measured, the measurement ranges, accuracies and associated instrument modes.

System Overview

The ERS-1 system is conceived to be a complete Remote Sensing System comprised of two elements:

- the Space Segment consisting of an ARIANE launcher, the satellite and its associated ground support equipment
- the Ground Segment encompassing the facilities implemented, operated and coordinated by ESA and a number of decentralized facilities to be implemented and operated by the users.

The main elements of the System are presented in figure 1.

At system level there are also less tangible interrelated efforts needed to support the hardware elements, such as the operational design aspects, the supporting software (for both space and ground segments), the overall system implementation and verification approach, and the diverse interfaces of the system design.

Data Flow and Data

The overall data flow shown in figure 2 covers both the control and information data paths within and between both the satellite and the ground segment. The primary control function resides with the Mission Control Center at ESOC which is linked via the ESA S-band network to the on-board computer. This computer is linked to the payload instruments, the instrument data handling and transmission and the platform subsystems by a data bus.

The data produced by the pulsed measurements of the instrument sensors is supplemented with specific user oriented house-keeping data and transmitted in real-time or as playback from the tape recorder to ground via two X-band channels. The ground segment oversees the acquisition and processing of the payload data for rapid-service products and quality monitoring, for later precision processing and archiving, and for product dissemination to the users. There will be one prime ERS-1 dedicated data receiving station (also used as the TT&C station) located at Kiruna in Sweden for its superior coverage characteristics. It is expected, that a number of additional Earthnet or national facility stations such as Fucino, Maspalomas, Churchill, Fairbanks will supplement the Kiruna station.

The data output of the Kiruna Station comprises Fast Delivery and Other Deliverable Products:

Within the group of Fast Delivery Products are:

- SAR Images
- Wave Spectrum Products
- Wind Field Products which comprise:
  - . wind velocity suproducts
  - . wind direction subproducts
- Significant Wave Height Product
- General and Instrument Header Products consisting of platform telemetry, house-keeping and auxiliary data which have been recorded on-board the satellite
- Performance Assessment Products which are data extracted from payload data to support instrument performance assessment.

Other Deliverable Data Products that can be obtained are:

- Raw Data down linked on X-band on High Density Digital Tape (HDDT).
- ATSR/M annotated Data on Computer Compatible Tapes (CCT) also received on the X-band downlink.

Operations

The satellite will be launched from Kourou Space Center into a 777 km circular, sun-synchronous orbit, and three axis stabilized with a nadir orientation. The nominal ERS-1 orbit is the 3-days repetition orbit with 14 and 1/3 orbits per day and a revolution time of 100.465 min.

The initial acquisition events - deployment of the solar array and antennas, satellite orientation and stabilization - are performed in a pre-programmed sequence by the platform. After a commissioning phase, the routine phase begins, during which the system will provide for a variety of instrument operational modes interrupted sporadically by orbit correcting manoeuvres.

The first mission will be experimental/pre-operational. Despite this nature of the first mission it will also have as an objective the demonstration of the operational capability of the ERS-1 system, i.e.: to supply timely data to its commercial or public service users.

2. SPACECRAFT AND PAYLOAD SUPPORT

The ERS-1 Satellite in deployed configuration is shown in figure 3. The main technical data are given in table 2.

A key element and constraint in the satellite concept is the utilization of an existing design platform. It was developed as a MULTIMISSION PLATFORM for the French SPOT program. This module provides standard services such as power supply, attitude and orbit control, data handling, spacecraft command and control function and the mechanical load interface to the launcher.

The platform per definition provides for a certain flexibility in standard service capabilities allowing, to a limited extent, an individual adaptation of these to the particular needs of a special payload. This mainly refers to the payload mass properties, size of the solar array, hydrazine tank capacity for attitude and orbit manoeuvring and onboard computer memory capacity.

The PAYLOAD consists of two major structural elements as shown on the sketch on the next page.

- Payload Electronic Module (PEM) in which, on four hinged side panels, the payload electronics units are mounted. This allows both easy access to the interior of the PEM, and also modular integration of sets of equipment preassembled on such panels. The electronics module houses in addition to the individual instrument electronics also a separate Instrument Data Handling and Transmission system (IDHT) as well as the payload related power distribution elements.
- Antennae Support Structure (ASS) which provides the mechanical interface points for the payload appendages. The precise instrument pointing requirements call for a thermostable antennae support structure, which is designed utilizing CFRP tubes with titanium nodes.

The Payload Thermal Control is basically achieved by a passive system supported by a set of heaters.

3. CORE PAYLOAD INSTRUMENTS

Active Microwave Instrument

The Active Microwave Instrument is a remote sensing radar operating in C-band and capable of performing three distinct functions corresponding to desired measurements and output products:

- Image Mode: When operating in the image mode the AMI performs as a synthetic aperture radar (SAR) producing high quality wide swath imaging over ocean, coastal zones and land. The SAR uses a side looking antenna and combines signals of the moving satellite borne antenna to effectively form a long antenna with high azimuthal resolution. The range resolution is achieved by an appropriate pulse length. Pulse compression technique reduces the peak power level requirements.
- Wave Mode: When operating in wave mode, the instrument will measure the change in radar reflectivity of the sea surface due to the ocean surface waves. In the wave mode the SAR is used at lower power for determination of two-dimensional ocean wave spectra of SAR images. This is achieved by using a different pulse length. The wave mode may be interleaved with the wind scatterometer measurements.
- Wind Mode: While operating in the wind mode, the instrument will act as a scatterometer and measure the change in radar reflectivity of the sea surface due to the perturbation of the surface by the wind close to the sea. The wind mode uses three antennas looking 45°, 90° and 135° with respect to the flight path. Basically a forward, a mid and an aft beam measurement must be made for every target. The three measured reflectivities are introduced in a mathematical model function which relates wind properties and ocean surface reflectivity to determine wind speed and direction. Azimuthal resolution is given by the antennas azimuthal beam width. Range resolution is established by range gating.

The block diagram in figure 4 shows the major elements of the AMI. The main technical parameters are given in table 3.

Radar Altimeter

The Radar Altimeter is a nadir looking active microwave instrument. Over ocean it is used to determine the significant waveheight, the wind speed, and the mesoscale topography. Over ice it is used to determine the ice surface topography, ice type, and sea/ice boundaries.

The microwave measurements comprise the time delay between transmission and reception of a pulse, the slope of the leading edge of the return pulse, the amplitude of the return pulse, and the echo waveform. These measurements are used as follows:

- the altitude is determined from the measured delay time after correction of propagation delays caused by ionosphere and troposphere; these corrections can be taken from measurements made by ATSR/M and/or PRARE. Absolute calibration will be performed by

using the Laser Retroreflector during zenith overflights over a laser ranging station

- the significant ocean waveheight (SWH) will be calculated from the slope of the leading edge of the return echo
- the wind speed over sea surfaces will be estimated from the power level of the backscatter signal; furthermore, the location of sea/ice boundaries can be derived.

In addition, the instrument will provide, for scientific use, echo waveform measurements averaged over 50 msec.

The technical characteristics of the ERS-1 Radar Altimeter are given in the table above. Figure 5 shows the block diagram of the instrument. Main technical data are given in table 4.

Laser Retroreflector

The Laser Retroreflector will permit the accurate determination of the satellite height by the use of a Laser Ranging Station. The measurements will be utilized for the calibration of the Radar Altimeter in zenith overflight and for improvement of the satellite orbit determination with respect to the radial component during normal satellite tracking.

To achieve these requirements, the Laser Retroreflector will consist of an appropriate number of retroreflecting elements, the so called corner cubes. For ranging of the satellite, monochromatic light pulses of associated laser ranging stations are emitted toward the Laser Retroreflector on the satellite. A fraction of the received pulses is reflected back by the corner cube arrangement towards the emitting laser station. By measuring the time delay between the emitted and received pulse, the distance from the laser station to the satellite can be established.

4. SCIENTIFIC PAYLOAD INSTRUMENTS

Along the Track Scanning Radiometer and Microwave Sounder (ATSR/M).

The ATSR is a passive instrument which consists of an infrared radiometer viewing from two directions and measuring in three infrared wavelengths. The objectives are to determine:

- sea surface temperature
- cloud top temperature
- cloud cover computations
- land and ice surface radiances
- investigations of day time sea-state from sun glint.

Combined with the ATSR is a microwave sounder viewing in the nadir direction using an offset fed 60 cm antenna operating at 23.8 GHz and 36.5 GHz. The major objectives of this instrument are to determine:

- total atmospheric water vapor content
- liquid content and rain areas
- land and ice surface emissivity

Precise Range and Range Rate Equipment (PRARE).

The PRARE will provide precise range and range rate data by two way measurements between ground stations and the satellite. The microwave instrument radiates in X-band with some functions in S-band. The propagation delays between transmission and reception in X-band are measured and stored on board the satellite and dumped via the PRARE command station. The on ground calculated time delay difference between S- and X-bands, which yields an ionospheric correction factor, can also be transmitted to the satellite for on board storage and later retrieval.

5. INSTRUMENT DATA HANDLING AND TRANSMISSION (IDHT)

To handle the very high instrument data rates of the satellite a specific Instrument Data Handling and Transmission system, operating in X-band, is included in the payload. It supplements the platform S-band data transmission system. The block diagram is shown in figure 6. The main technical data are given in table 5.

The IDHT is subdivided in three subsections dedicated to definite functions:

- a data handling subsystem
- a recording subsystem
- a transmission subsystem

. The data handling subsystem has two functions

- with the Intelligent Control Unit (ICU) it controls the correct command execution and dialogues with the on board computer
- with the Data Control Unit (DCU) it controls the instrument data flux over high speed and medium speed channels.

. The recording subsystem consists of two redundant tape recorders in order to cover all measurement modes except SAR imaging during one orbit. Data is normally recorded in continuous mode, so that only few starts stops of the recorders are foreseen. The data is already formated in one direction and then reproduced for transmission in the reverse direction.

. The transmission subsystem uses two independent links for data transmission:

- Link one for high speed data transmission in real time
- Link two for medium speed data transmission in real time and/or transmission of playback data.

The IDHT is designed to operate in the following modes:

- Mode 1: Acquisition and transmission in real time of high speed data from AMI in SAR imaging mode.
- Mode 2: Acquisition and transmission in real time of medium rate data.
- Mode 3: Acquisition and storage of all medium speed instrument data.
- Mode 4: Playback and transmission of the recorded data.

Combinations of the above modes are possible as follows:

- Mode 2 and 3 simultaneously
- Mode 2 and 4 simultaneously
- Mode 1 is independently selectable with respect to the other possible modes or mode combinations.

In order to provide an additional transmit capability for all medium speed data (e.g. all instrument data except SAR imaging) an optional L-band transmission chain is also under consideration.

6. THE GROUND SEGMENT

The Ground Segment has the joint tasks of controlling and monitoring the satellite throughout the mission and of payload data management including reception, processing, dissemination and archiving. The overall concept is shown in figure 7. In particular the Ground Segment performs the following main functions:

- Control and monitor the satellite and the associated elements
- Acquire all data on the downlinks
- Generate and distribute selected products in near real time
- Generate and distribute fully corrected products and perform the associated archiving
- Calibration activities and quality control functions.

The communication with the satellite will be performed by four different links:

- Uplink in S-band for telecommands and ranging
- Downlink in S-band for telemetry and ranging
- Downlink in X-band for SAR Image Mode data (Link 1) in real time with approximately 100 Mbps
- Downlink in X-band for all other instrument data (Link 2) in real time (approx. 1 Mbps) and playback from the on board tape recorder (approx. 15 Mbps)

and an optional fifth link

- Downlink in L-band for all low-rate data for reception by Tiros-like stations.

To fulfil these functions the Ground Segment will be composed of the following major elements shown in the diagram on the left:

- Mission Management and Control Center (MMCC)
- TT&C S-band network (ESANET)
- Data Acquisition and Processing Facility (DAPF)
- Real time Data Acquisition Facilities (RDAF) and/or DAPFs
- Processing and Archive Facility (PAF)
- Primary and end user Facilities.

The MMCC located at ESOC and supported by ESANET is responsible for:

- Control and monitoring of the satellite and the Kiruna Station
- Mission planning
- Generation and distribution of auxiliary information such as orbit and attitude data.

The TT&C station to be installed at Kiruna (Sweden) will be dedicated to ERS-1 but will be a standard ESANET station except for the antenna which will be shared with the DAPF.

In addition Kiruna acts as a reference station so that it also includes link performance measurement equipment on S- and X-band.

The general composition of the DAPF is as follows:

- Data Acquisition (DAF)
- Real time Processing Facility (RTPF)
- Product Distribution Facility (PDF)

The DAF will acquire all playback data from the on board recorder, the real time low bit rate data and the SAR data within the station visibility. The DAF comprises besides the X-band receiving equipment the feeds and amplifiers for S-band up- and downlink. The DAF is completed by High Density Digital Recorders (HDDR) for recording all acquired data.

The RTPF comprises three subsystems:

- A SAR Fast delivery processing S/S
- A low rate data processing S/S
- A station control S/S

The processing S/S will generate out of the acquired raw data the following products in real time:

- Surface wind field
- Significant wave height
- Wave image spectrum
- Fast delivery SAR images
- Results of quality control processing.

The station control S/S will provide the interface to the MMCC, monitor the performance of all equipment, report their status, perform detailed scheduling and control and allocate the resources.

The PDF comprises the equipment necessary to format the products for transmission within the required delay time to MMCC, primary users and PAF.

The ERS-1 Ground Segment will be complemented by a number of ESA and non ESA facilities such as:

- RDAF and/or DAPF outside the coverage area of the Kiruna station
- PAF
- TT&C station for back-up and LEOP

These facilities may comprise already existing instalations and are not necessarily ERS-1 dedicated.

7. REFERENCES

ERS-1 Proposal for Phase C/D, Volume 1, Executive Summary, September 1983.

Table 1
ERS 1 Main Geophysical Measurement Objectives

Main Geophysical Parameter	Range	Accuracy	Main Instrument
Wind Field			
Velocity	4 24 m/s	± 2 m/s or 10 % whichever is greater	Wind Scatterometer & Altimeter
Direction	0 360 deg	± 20 deg	Wind Scatterometer
Wave Field			
Significant Wave Height	1 - 20 m	± 0,5 m or 10 % whichever is greater	Altimeter
Wave Direction	0 360 deg	± 15 deg	Wave Mode
Wavelenght	50 - 1000 m	20 %	Wave Mode
Earth Surface Imaging			
Land/Ice/Coastal zones etc	80 km (minimum swathwidth)	Geometric/Radiometric Resolutions a) 30 m/2 5 dB b) 100 m/1 dB	SAR Imaging Mode
Altitude			
Over ocean	745 - 825 km	2 m absolute ± 10 cm relative	Altimeter
Satellite Range		± 10 cm	PRARE
Sea Surface Temperature	50 km swath	± 0 5 K	ATSR (IR)
Water Vapour	in 25 km spot	10 %	μW Sounder

Figure 1:
System Overview

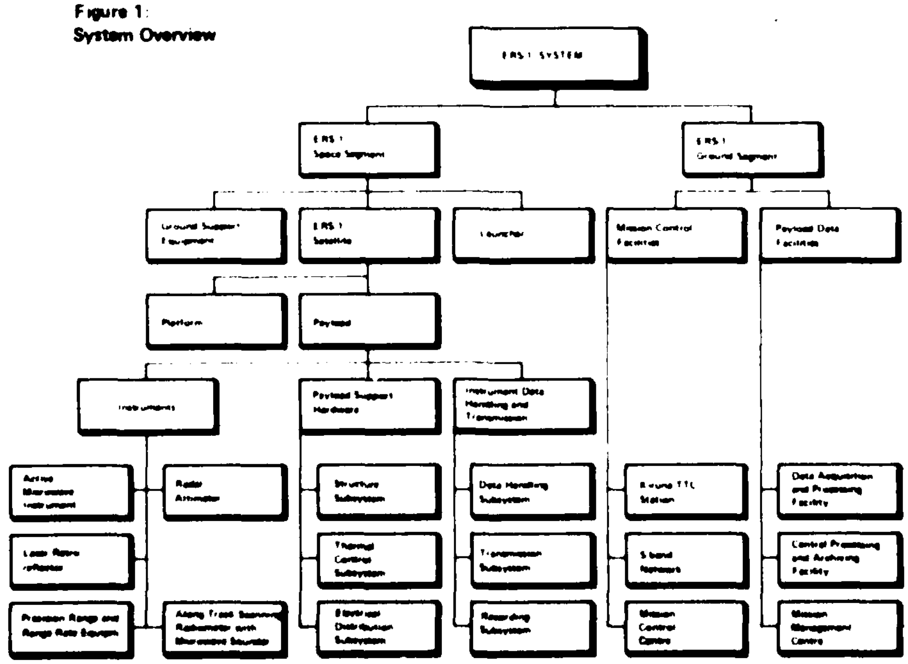


Figure 2:
Overall Data Flow

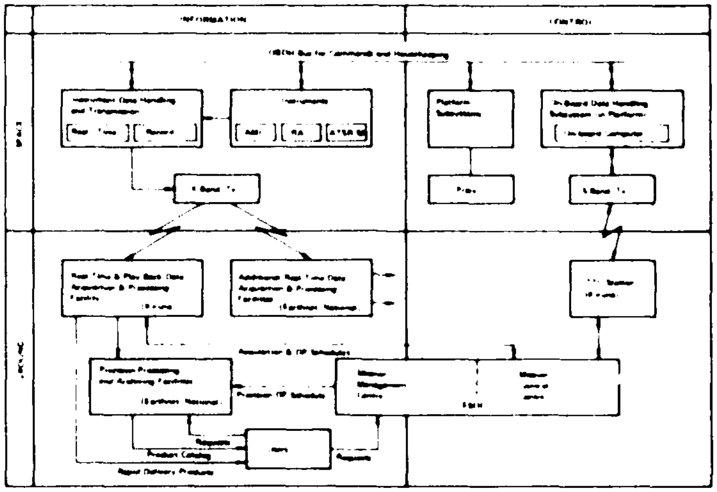


Figure 4:
AMI Block Diagram

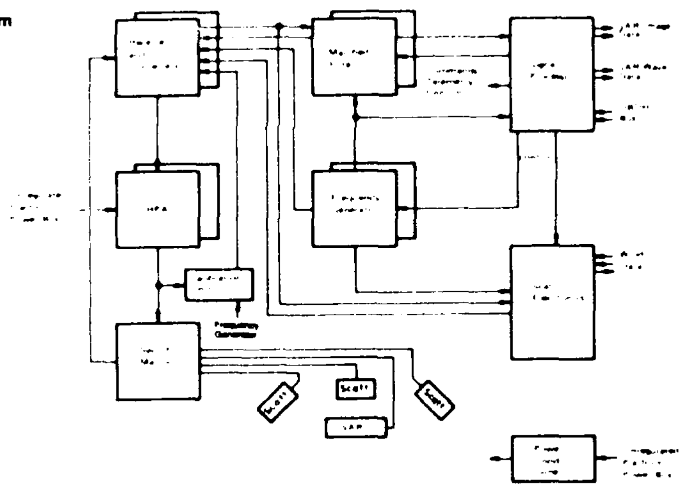


Table 3:
Main AMI Data

Radar Frequency	5.3 GHz	Resolution Cell	
Peak RF Power	4.8 kW	SAR Wave	5 x 5 km^2
		Wind	50 x 50 km^2
Mean RF Power			
SAR Imagery	300 W	DC Power	
SAR Wave	100 W	SAR Imagery	1220 W
Wind Scatt	113 W	SAR Wave	240 W
		Wind	430 W
Swath Width			
SAR Imagery	80 km	Data Rates	
SAR Wave	5 km	SAR Imagery	< 103 Mbs^{-1}
Wind	500 km	SAR Wave	800 kbs^{-1}
		Wind	120 kbs^{-1}
Resolution Cell			
SAR Imagery	30 x 30 m^2	Total Mass	340 kg

Figure 3

ERS-1 Satellite

(Antennae and Solar Array deployed)

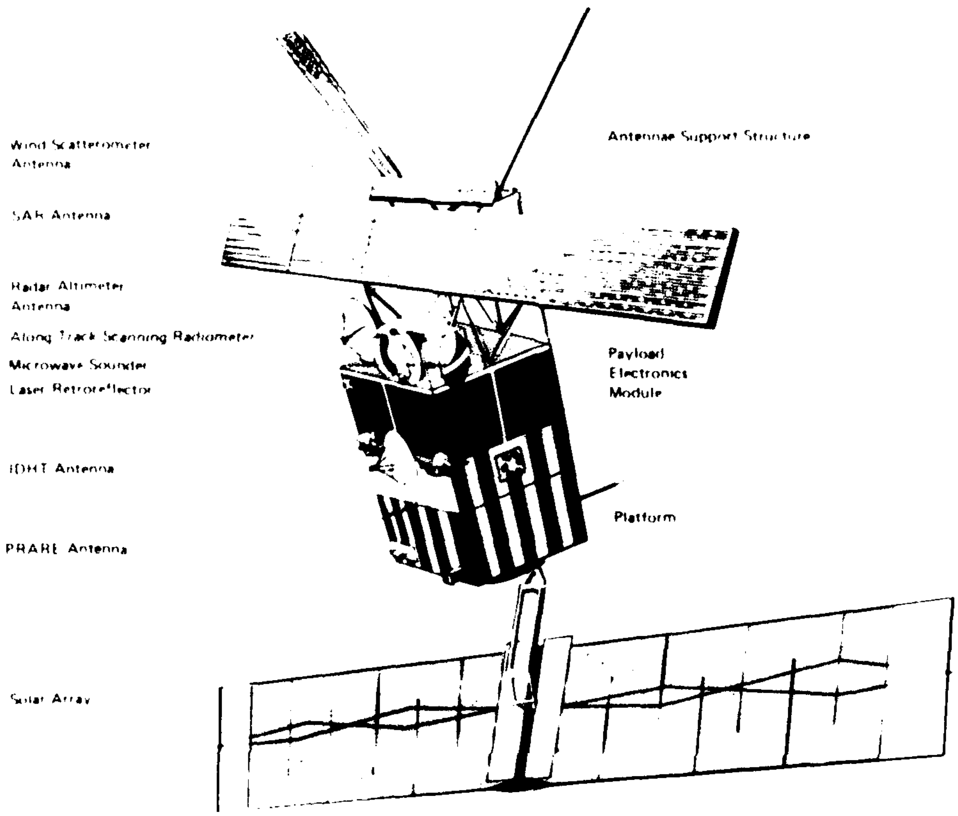


Table 2

Main Satellite Data

Structure

- Payload Electronics Module (PEM)
  - Box structure
  - 9 vertical titanium beams
  - Load carrying side panels, top panel, and compartment panels in aluminium sandwich
- Antenna Support Structure (ASS)
  - Framework of CFRP struts with titanium nodes and fittings

Thermal Control

- Passive desgin with
  - SSM covered radiators on + Y and + Z faces
  - All areas covered with MLI except radiator areas
  - ASS, ATSR-M, AMI HPA Radiator, and Platform thermally decoupled from electronics module
  - Heat pipes in AMI HPA Radiator
  - ASS wrapped in superinsulation
  - PEM interior painted black
  - Redundant guard heater system, controlled by thermostats
  - Housekeeping thermistors

Instrument Data Handling and Transmission (IDHT)

- Data storage 6.5 Gbit
- *2 Tape recorders*
- Payload telemetry bit rates (scientific)
  - high rate 100 Mbit/sec
  - medium rate realtime 5 Mbit/sec (spread)
  - medium rate playback 15 Mbit/sec
- Data formats
  - Engineering data multiplexed with scientific data
  - One format for high rate data
  - One format for medium rate data

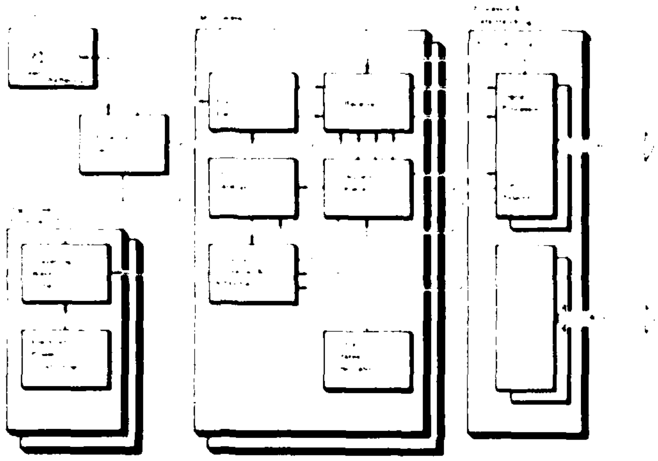
Platform

- Satellite support functions
  - Power supply distribution, pyrotechnics
  - Payload peak power 2600 W
  - Payload permanent power 550 W
  - Voltage 23-27 V
  - Onboard energy 2650 Wh max
  - Attitude and orbit control
  - 3 axes stabilized without onboard momentum
  - Pointing error: biases 0.07 deg
  - non biases 0.07 deg
  - Onboard impulse 620 000 Nsec
  - Communications
  - Transponder coherent S Band
  - Transmitter power 50-200 mW
  - Telemetry rate 2048 bit/sec
  - Telecommand rate 2000 bit/sec
  - Data handling
  - OBC word length 16 bits
  - Payload memory 20 kwords
  - 5 redundant payload users
  - OBDH type bus

Spacecraft Mass and Dimensions

- Payload Mass 900 kg
- Platform Mass 1260 kg
- Spacecraft Mass 2160 kg
- Overall Height 11.8 m
- Overall Length 11.7 m
- Central body 1.9x1.9x3.0 m
- Solar Array 11.7x2.4 m
- SAR Antenna 10.0x1.0 m
- Scatterometer Antenna 3.6x0.3 m
- RA Antenna 1.2 m DIA

Figure 5
Radar Altimeter Instrument Blockdiagram



Main Radar Altimeter Data

Measurement Frequency	13.7 GHz (K_U Band)
Measurement Principle	Full Deramp Concept
Chirp Length	20 μsec
Bandwidth	330 MHz
Peak Transmit Power	50 Watt
Pulse Repetition Freq.	1 KHz
Onboard Signal Processor	Suboptimum Maximum Likelihood Estimator
Paraboloid Antenna	1.2 m Diameter
Total Mass	96 kg
DC Power Consumption	134 W
Data Rate	15 KBit/sec

Figure 6
IDHT Functional Block Diagram

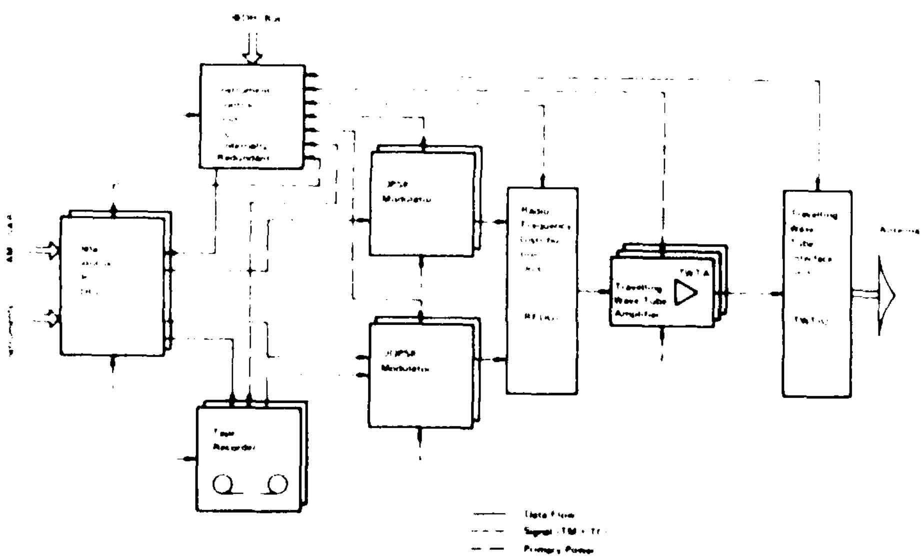


Table 5:
IDHT Main Data

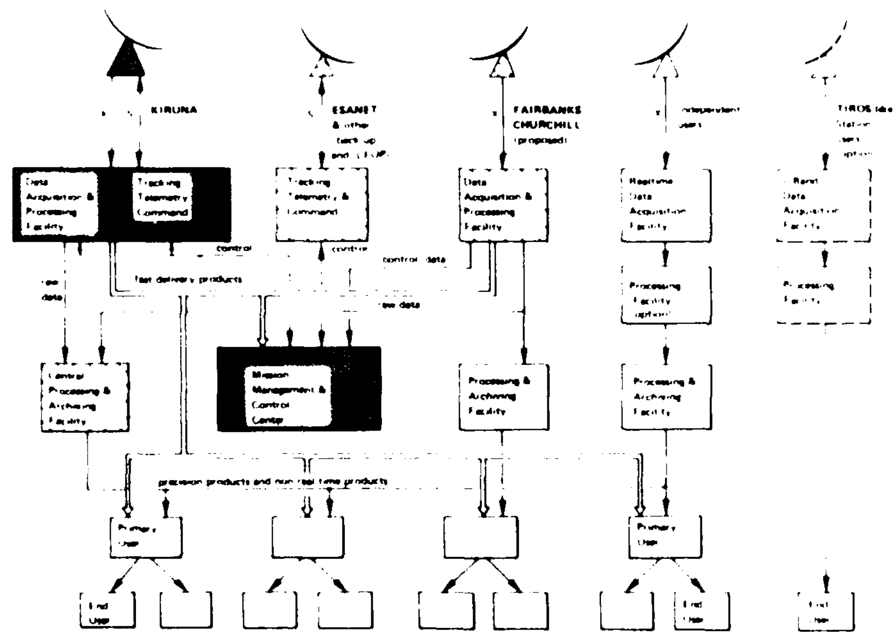
IDHT without optional L band transmission system

- Mass 75 kg
- Prime Power Consumption max 285 W
- RF Output Power per link 20 W

Optional L band transmission system

- Mass 1.5 kg
- Prime Power Consumption max 50 W
- RF Output Power max 5.5 W

Figure 7:
The Overall Ground Segment Concept



The discussion which followed this presentation appears in classified publication CP 344 (Supplement)

A MODERN APPROACH OF A SYNTHETIC APERTURE RADAR PROCESSOR AND ITS TECHNOLOGICAL ASPECTS

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SUMMARY

A flexible hardware concept is presented which allows to handle high speed image processing tasks. The concept is applied to a realtime SAR-Processor covering C-band ERS-1 as well as X-band MRSE radar data.

After a short introduction to the SAR principles and the SPECAN-algorithm which is made use of in the processor breadboard, some of the basic hardware processing modules and its performance data are described in more detail (Storage Unit, FIR Filter/Correlator, Complex Multiplication, Fast Fourier Transformation, Pipeline Controller).

The performance data show that high speed image processing can be implemented at low power consumption and small volume. Due to the universal concept cost can also be kept down for this class of processing tasks.

1. INTRODUCTION

A modular, realtime SAR-Processor Breadboard is presently being developed by DORNIER under contract of DFVLR and funded by the German Ministry of Research and Technology (BMFT). The digital ground processor resulting from these activities shall be able to produce twodimensional SAR images taking raw radar data of the German X-band radar system MRSE (Microwave Remote Sensing Experiment) as well as the C-band ESA-ERS 1 system. Additionally, further adaptability of the processor to airborne SAR-systems shall be possible.

The basic features of the processor are given by the image requirements listed in Table 1-1 which are regarded to be a common baseline for earth exploration purposes within ESA (European Space Agency) and DFVLR (German Authority for Aerospace Research). Furthermore, the processor concept is strongly influenced by a high throughput demand (realtime processing) at low power consumption rates in order to allow for a future upgrading of the processor to spaceborne/airborne applications.

Finally, a high modularity and, if possible, repeatability of functional groups within the processor is required for reasons of cost reductions and simple maintainability.

The SAR-Processor Breadboard fullfilling the above mentioned requirements will be implemented in different steps. A first model allowing the realtime processing of true raw radar data will be available in spring 85. The overall control parameters of this processor, however, must be keyed-in manually. A fully automatic version of the processor including a Mean Doppler Estimator and a link to the beam pointing measuring system of the platform is planned to be ready for tests at the end of 1985.

2. SAR-PRINCIPLES AND SPECAN-ALGORITHM

The principle geometry of a Synthetic Aperture Radar is shown in Fig. 2-1. The SAR antenna transmits RF pulses in the direction perpendicular to the velocity vector of its platform. Any target located within the beam of the antenna will contribute to the overall received signal according to its radar reflectivity. In order to resolve the reflectivity distribution of the ground down to the required dimensions (spacial resolution) processing in both range and azimuth direction is necessary.

Range discrimination of targets is performed by making use of the different two way propagation delay of reflectors located at different range coordinates. However, a pulse compression of the extended transmitter pulse (e. g. a linear chirp signal) must be included to attain the required ground range resolution (see Fig. 2-2).

The azimuth response of each point target is given by the linear movement of the antenna. The frequency behavior of the received azimuth signal can be understood to be the Doppler-shifted RF frequency of the transmitted pulse when the antenna approaches or leaves the target. A hypothetical omnidirectional antenna would result in a frequency versus time diagram as shown in Fig. 2-3 with the carrier frequency of the RF signal already been removed in this plot.

A more realistic, pencil-beamed antenna cuts only a short portion out of the diagram of Fig. 2-3. Since the antenna normally points nearly perpendicular to the antenna velocity vector, the cut is located within the linear area of the diagram of Fig. 2-3. Therefore, a linear chirp signal is expected as being the azimuth response of a point target as well. Again, a pulse compression in azimuth must be performed in order to arrive at the required spacial azimuth resolution.

The azimuth compression of a SAR processor, however, differs in two points from the range compression. First, the replica length of the azimuth compression normally is shorter than the respective length of the range compression which may result in different compression techniques. Second, the raw radar data are sampled in range direction. Therefore, the data must be rearranged before the azimuth compression can be performed. The operation, which changes the sampling direction from range to azimuth is called Corner Turning. It is implemented by means of an appropriate memory.

If the available signal bandwidth either in azimuth or in range direction exceeds the minimum value which is necessary for achieving a given spacial resolution, Look Summation can be introduced in order to reduce speckling and noise effects of the measured reflectivity amplitude.

Finally, the range migration of the energy of any point target due to earth rotation and antenna mispointing must be compensated for. For X- and C-band radars the range walk can be regarded to be a linear function of time which causes remarkable simplifications of the SAR-Processor.

Fig. 2-4 shows a simplified block diagram of the general structure of a SAR-Processor as described above. Additional functions like Recorner Turning and Postprocessing must be included to rearrange the output data in range direction and to assure that both directions are scaled equally.

Different algorithms are available for the compression of the raw radar data both in range and azimuth:

- filtering in frequency domain
  (FFT, multiplication, inverse FFT)

- filtering in time domain
  (correlation)

- SPECAN algorithm
  (multiplication, FFT)

Previous investigations performed under an ESA contract (Spectral Analysis Approach to the Compression of linear FM Signals, ESTEC contract 3998/79/NL/HP (SC), TN-79-276-003) resulted in the conclusion that the SPECAN algorithm is most favorable for the azimuth compression of C- and X-band radars. Therefore, this concept has been used in the SAR-Processor Breadboard and is shortly described in what follows:

If the azimuth doppler history of several adjacent targets is multiplied by a reference function the slope of which is opposite to the slope of the doppler history, the chirp of each target is transformed to a monofrequency signal as described in Fig. 2-5. In order to compute the amplitude of each signal a Fourier Transformation (FFT) is applied to the dechirped signals. The length of the FFT operation defines the azimuth resolution of the processed targets.

3. PROCESSOR ARCHITECTURE

The architecture of the SAR-Processor Breadboard is shown in Fig. 3-1. It consists of a high speed radar data processing pipeline including the hardware modules

- Range Cell Migration Correction (RCMC)
- Reference Function Multiplication (RFM)
- Corner Turn Memory (CTM)
- Fourier Transformation (FFT)
- Look Summation (LS)
- Postprocessor (POPR)

which performs the azimuth compression and look summation of 1024 range samples (approx. 20 km swathwidth) at an input data rate of 2 Mwords/sec. Identical pipelines must be paralleled if more than 20 km shall be processed in realtime.
Range compression of the sensor data is not included in the present design of the breadboard since onboard range compression was assumed at the time when the architecture had been determined.

The fast processing pipeline is controlled by three medium speed control modules which provide for the parameters required by the pipeline modules. At this control level control data must be computed at a rate of typically 2 - 10 Kwords/sec depending on the module and the SAR-sensor itself.

Finally, a microprocessor controller links the SAR-Processor to the slow speed overall system parameters (operator resolution and look definition, Mean Doppler and FM-Rate of radar data, antenna heading) which are needed in order to define the basic inputs to the processor. The data rate at this point is some words per second.

The Mean Doppler frequency of the radar data must be determined from the data itself by a Mean Doppler Estimator module for a fully hands-off operation. This is due to the fact that the primary information (mainly the antenna pointing angles) cannot be measured to the accuracy which is required to compute the Mean Doppler frequency from those data.

4. IMPLEMENTATION OF THE PROCESSOR

The implementation of the processor is accomplished under the aspect that each specifically designed hardware module must include enough commonality and flexibility to make it a part of a more general signal processing hardware family. This concept allows the functional modules to be used at several places of the processor (e. g. see Storage Unit) or even supports the implementation of different image processing tasks (e. g. other SAR-algorithms, pattern recognition etc.) at very low development cost using the same hardware modules in different arrangements.

Some of the more important modules of the SAR-Processor Breadboard are described in more detail in the subsections below.

4.1 High Speed Storage Unit

Intermediate storage of data frames is one of the most important functions of any kind of image processing. In a SAR-processor those memory units are used during Corner Turning, Look Summation, Recorner Turning, video display storage and test pattern generation. In order to cover these applications a universal memory board has been developed which allows for writing and reading line based image data in both range and azimuth direction. The length of each line can be programmed within the total capacity of 256 Kwords, where the word length can be any value up to 16 bit.

The memory boards can easily be cascaded if more than 256 Kwords of memory size is required.

Dynamic NMOS memory chips (64 k 1) and TTL-ALS control circuits are used for the board, the size of which is 233 x 160 mm^2. A write/read speed of up to 3 Mwords/sec could be achieved at a power consumption of 3.2 Watt. Refresh circuits for the dynamic memory chips are included on the board.

A complete memory system (e. g. CTM) is built up of 3 memory boards and a simple controller board which provides for the correct input/output interface and some trigger signals which tell the memory boards when to write/read frames.

4.2 Finite Impulse Response Filter

FIR filters are widely used for low pass filtering, bandpass filtering (in combination with a complex premultiplication), digital interpolation and correlation. In a SAR-processor, digital interpolation/resampling is required for the Range Migration Compensation module as well as for the Postprocessing module.

A FIR filter offering programmable length of up to 16 samples at a word length of 8 bit (data and coefficients each) has been developed using a TRW multiplier/accumulator circuit and TTL-ALS control logic on a standard 233 x 160 mm^2 board. Subsampling of the output signal is possible if the FIR filter is used as a lowpass filter.

The maximum input data rate is given by the internal 12 MHz computation clock, the filter length and the chosen subsampling factor. At a full filter length of 16 (no subsampling), the input rate can be up to 0.72 Mwords/sec. The power consumption is 4.6 Watt.

The filter coefficients are stored in a 2 K x 8 PROM offering a large variety of different, selectabl coefficient sets.

4.3 Complex Multiplication

A complex multiplication module has been developed on the basis of a fast TRW multiplier and some TTL-ALS control logic. The whole circuit is implemented on a board of the size 160 x 100 mm^2. It can be operated up to an input data rate of 3 Mwords/sec. The power consumption turned out to be 3.0 Watt including output rounding and saturation limitation circuits. Data word length is 8 bit at both input and output.

This unit is used as the Reference Function Multiplication module of the SAR-Processor Breadboard. However, other applications like premultiplication in a bandpass filter configuration have also been implemented with this module.

4.4 Fast Fourier Transformation (FFT)

A hardware FFT module is presently under design at DORNIER. It is based on the Radix 2 Decimation-in-Time algorithm showing the following features:

- complex input 8 I, 8 Q
- complex output 12 I, 12 Q
- programmable FFT length of 32-64-128-256-512-1024
- complex butterfly hardware element, operating at approx. 15 MHz
- FFT data addressing scheme downloaded from external device

This module will be able to perform the operations required for azimuth/range compression of the SPECAN method as well as of the frequency domain algorithm.

4.5 Medium Speed Pipeline Controllers

The pipeline controllers of the SAR-Processor Breadboard convert the more general control parameters (e. g. Mean Doppler Frequency, FM-Rate, Antenna pointing angles) into secondary control parameters which are used by the pipeline modules. The basic arithmetic operations are required in order to perform these transformations. Since the output data rates are around 2 - 10 Kwords/sec, a signal processor like the NEC 7720 is a favorite candidate for these jobs.

Fig. 4-1 shows a block diagram of the NEC 7720. It consists of a 16 bit ALU and two accumulators, a separate 16 x 16 bit fast multiplier, 512 x 13 bit programmable data ROM apart from the instruction ROM (512 x 23 bit). The instruction cycle time is 250 nsec at an internal frequency of 8 MHz.

The EPROM version NEC 77P20 allows for a flexible programming of both the instruction ROM and data ROM even for small numbers of chip pieces.

The part of the Range Controller which computes the reference function of the RFM module from the FM-Rate of the sensor has been implemented by software on the NEC 77P20. An output data rate of up to 28 Kwords/sec could be obtained which is much more than what is required for realtime processing (2 - 10 Kwords/sec).

Fig. 4-2 shows a scope plot of the real and imaginary part of the linear chirp function which is used as a reference by the RFM module.

5. GROWTH POTENTIAL OF CONCEPT

The hardware activities described above will result in a family of universal signal processing modules which can be arranged in such a way that a large variety of image processing tasks can be handled in realtime. The central members of the family are:

- Correlation
- Filter/Interpolator/Resampling
- Fourier Transformation
- Storage Unit
- Multiplication
- Accumulation
- Programmable Pipeline Controller

The modular concept assures a cost effective implementation of high speed processing tasks. Low power and volume design will allow this concept to be extended to more critical applications, e. g.

- mobile ground processing
- aircraft applications
- spaceborne applications

As compared to more conventional approaches to signal processing tasks using general purpose multiprocessor architectures the concept described above shows much higher processing efficiency due to the fact that data communication is neither limited by bus constraints nor by mass storage devices which normally must be used to preserve intermediate results of the processing algorithms. At the same time, weight and power consumption considerations turn out to favorite the flexible hardware concept as compared to a multiprocessor architecture as well.

The overall software programmability of a general purpose solution seems to be no real advantage because the cost of a software redesign of a complex processor architecture is well comparable to the cost of a rearrangement of hardware modules. This fact becomes even more interesting when modern computer aided design methods are introduced into the manufacturing process of hardware systems.

6. REFERENCES

"Spectral Analysis Approach to the Compression of Linear FM Signals". Technical Note TN-79-276-003, ESTEC contract 3998/79/NL/HP (SC), December 1979.

AZIMUTH RESOLUTION	25 M
GROUND RANGE RESOLUTION	25 M
SWATHWIDTH	80-100 KM
RADIOMETRIC RESOLUTION	1.5 DB
DYNAMIC RANGE OF PROCESSOR OUTPUT SIGNAL	> 60 DB
HIGHEST SIDELOBE LEVEL	< -20 DB
PROCESSOR INDUCED ARTIFACTS	< -30 DB
RADIOMETRIC DISTORTIONS	< ± 0.5 DB
OUTPUT DATA REGISTRATION ERRORS	< ± 1 PIXEL

TABLE 1-1: IMAGE QUALITY REQUIREMENTS FOR A TYPICAL EARTH EXPLORATION SAR-SYSTEM.

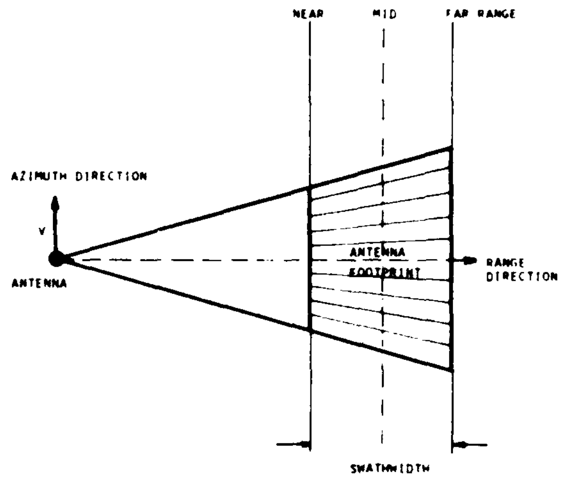

FIG. 2-1: AZIMUTH GEOMETRY OF A SYNTHETIC APERTURE RADAR SYSTEM.

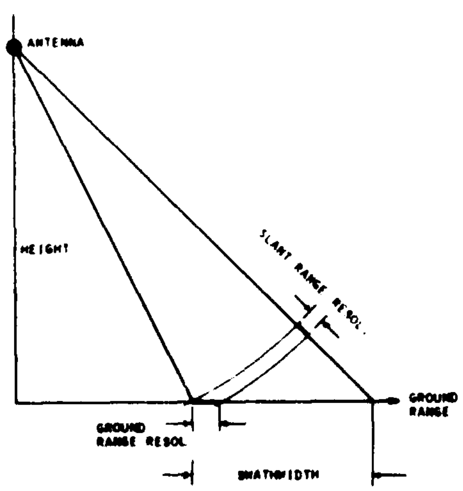

FIG. 2-2: RANGE GEOMETRY OF A SYNTHETIC APERTURE RADAR SYSTEM.

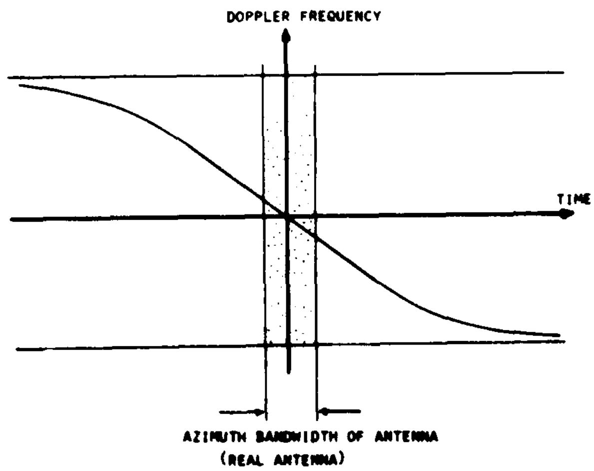

FIG. 2-3: AZIMUTH HISTORY OF A POINT TARGET FOR A HYPOTHETICAL OMNIDIRECTIONAL ANTENNA.

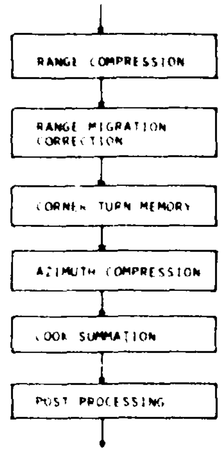

FIG. 2-4: FUNCTIONAL STRUCTURE OF A SYNTHETIC APERTURE RADAR PROCESSOR (SIMPLIFIED).

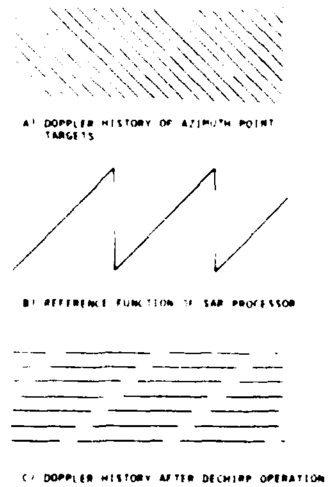

FIG. 2-5: PRINCIPLE OF SPECAN ALGORITHM

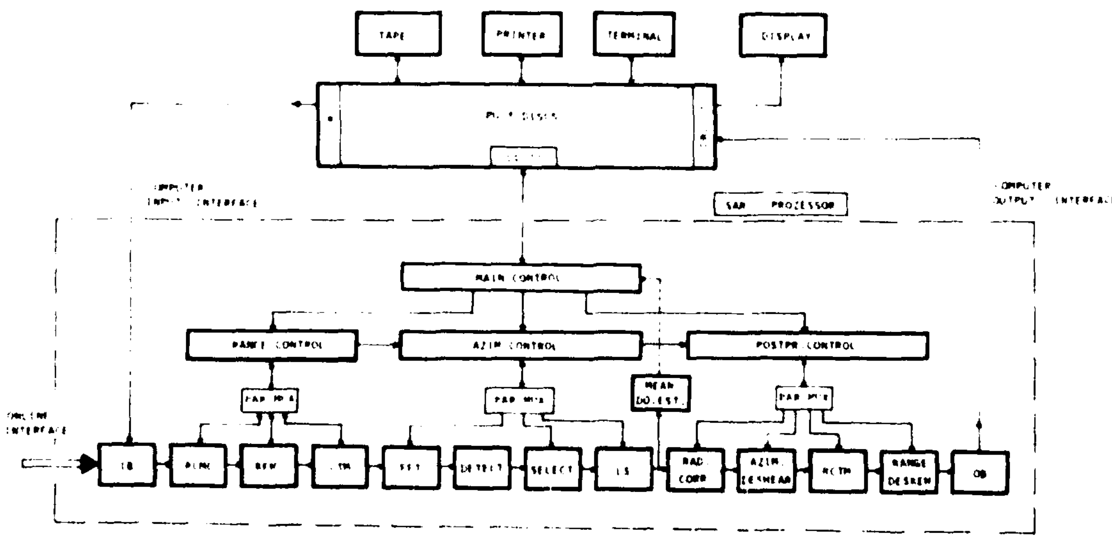

FIG. 3-1 BLOCK DIAGRAM OF SAR PROCESSOR BREADBOARD AND TEST FACILITY

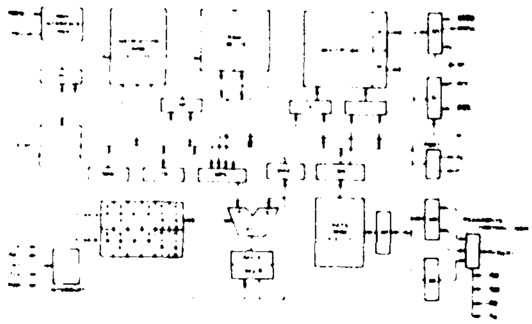

FIG. 4-1: BLOCK DIAGRAM OF NEC 7720 SIGNAL PROCESSOR.

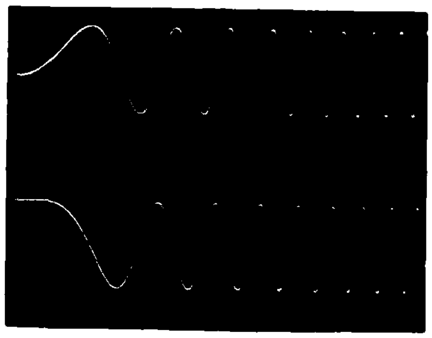

FIG. 4-2: REAL AND IMAGINARY PART OF THE REFERENCE FUNCTION GENERATED BY NEC 7720.

The discussion which followed this presentation appears in classified publication CP344 (Supplement).

EARTH RESOURCES RESEARCH USING THE SHUTTLE IMAGING RADAR SYSTEM

by

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ABSTRACT

The Shuttle Imaging Radar (SIR) is an L-band synthetic aperture radar that transmits and receives horizontally polarized microwave radiation. It was originally launched on the second Shuttle test flight (STS-2) in November 1981 with the antenna depression angle fixed at 43°. In this configuration, the radar system was referred to as SIR-A, and it collected more than ten million square kilometres of earth imagery in a variety of areas situated between 38° north and south latitude. SIR-A data was optically recorded onboard the Shuttle, and it was subsequently correlated on the ground to produce imagery with a 50 kilometre swath width and a surface resolution of approximately 40 metres. This data is currently available through the National Space Science Data Center, Greenbelt, Maryland, 20771. SIR-A obtained orbital radar coverage of many arid and tropical portions of the earth for the first time. Distinctive variations in radar backscatter observed in SIR-A imagery have been related to radar penetration of wind-blown sand, variations in the particle size of aeolian sand deposits, and variations in vegetation density and the architecture of vegetation canopies. Certain terrain characteristics detected in SIR-A imagery are potentially important for evaluating surface trafficability and identifying human disturbances of natural environmental conditions. The SIR is presently being upgraded into a new configuration termed SIR-B, in which the radar's antenna can be mechanically rotated in the Shuttle's payload bay during an orbital mission. SIR-B is currently scheduled for flight on the seventeenth Shuttle mission (STS-17) that is tentatively planned for August 1984. In its new configuration, the SIR-B can be used to image selected regions at different angles of incidence ranging from 15° to 60° (as measured from the local vertical). In principle, multiple incidence angle radar imagery of selected areas can be coreregistered and used to differentiate surficial materials on the basis of their roughness characteristics. This procedure is conceptually similar to the use of multispectral imagery acquired at shorter wavelengths to discriminate surficial materials on the basis of their pigmentation. Similar experiments have not been performed with airborne radar systems due to the large variation in incidence angle that occurs in the range direction (i.e. across the aerial swath). In contrast, orbital radar systems are uniquely able to image broad areas of the earth's surface at a nearly constant angle of incidence. SIR-B can potentially obtain data from 57° south to 57° north latitude. SIR-B data will be transmitted to the ground in real time via the Tracking and Data Relay Satellite System (TDRSS) where it will be digitally correlated. Future modifications of the SIR that are currently under consideration would provide for simultaneous collection of image data at multiple radar frequencies and the ability to measure the backscatter response of the earth's surface at multiple polarizations.

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14. Abstract

These Proceedings for the 46th Symposium/Meeting of the AGARD Avionics Panel are contained in two volumes. AGARD-CP-344 contains the Technical Evaluation Report and unclassified papers and abstracts. The NATO Secret AGARD-CP-344(S) contains the Technical Evaluation Report, classified papers, unclassified abstracts, round table discussions, discussions following the presentations of papers, and a list of participants. In the overview session five papers were presented by distinguished speakers. During the communications session ten papers were presented. The five papers presented during the navigation session all dealt with the NAVSTAR Global Positioning System. The session covering remote sensing had six papers discussing meteorological satellites. The final session on prospects for the future provided nine papers on a variety of subjects.

The objectives of the symposium were as follows:

a. Provide an overview of tactical needs which are effectively addressed by space systems.
b. Characterize the various existing and potential space systems with emphasis on those attributes which are most related to tactical needs.
c. Assess the advantages and limitations of space systems in supporting combat operations.
d. Investigate the interaction of space assets with ground and mobile resources and the consequent operational issues.
e. Discuss future trends in space technology and their relationship to evolving combat needs.

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